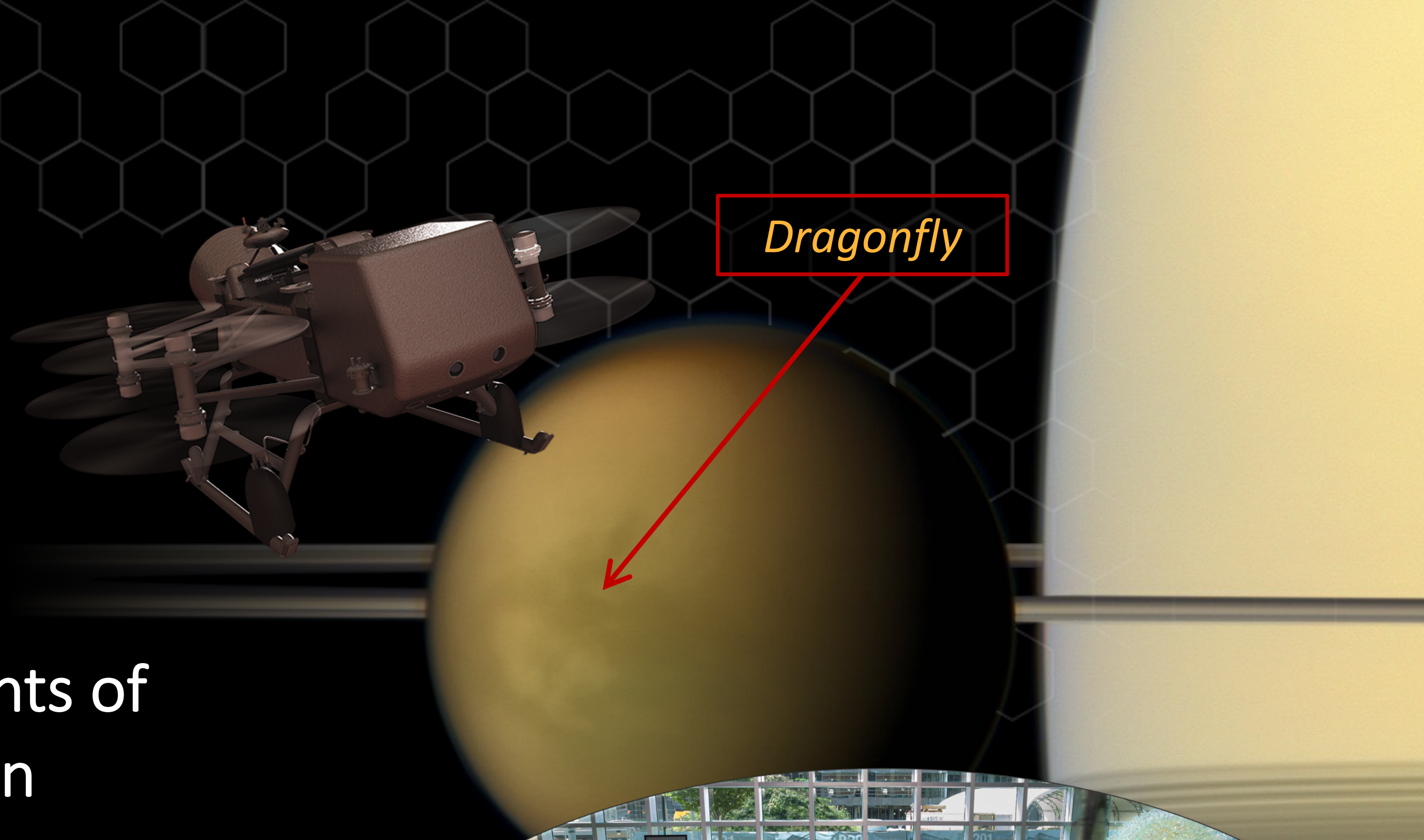
DRAGONFLY

A relocatable lander to explore Titan's prebiotic chemistry and habitability



Dragonfly: Designing for Flights of Exploration on an Alien Moon

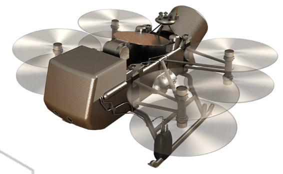
10 August 2021

Kenneth Hibbard, Dragonfly Mission Systems Engineer
Johns Hopkins Applied Physics Laboratory

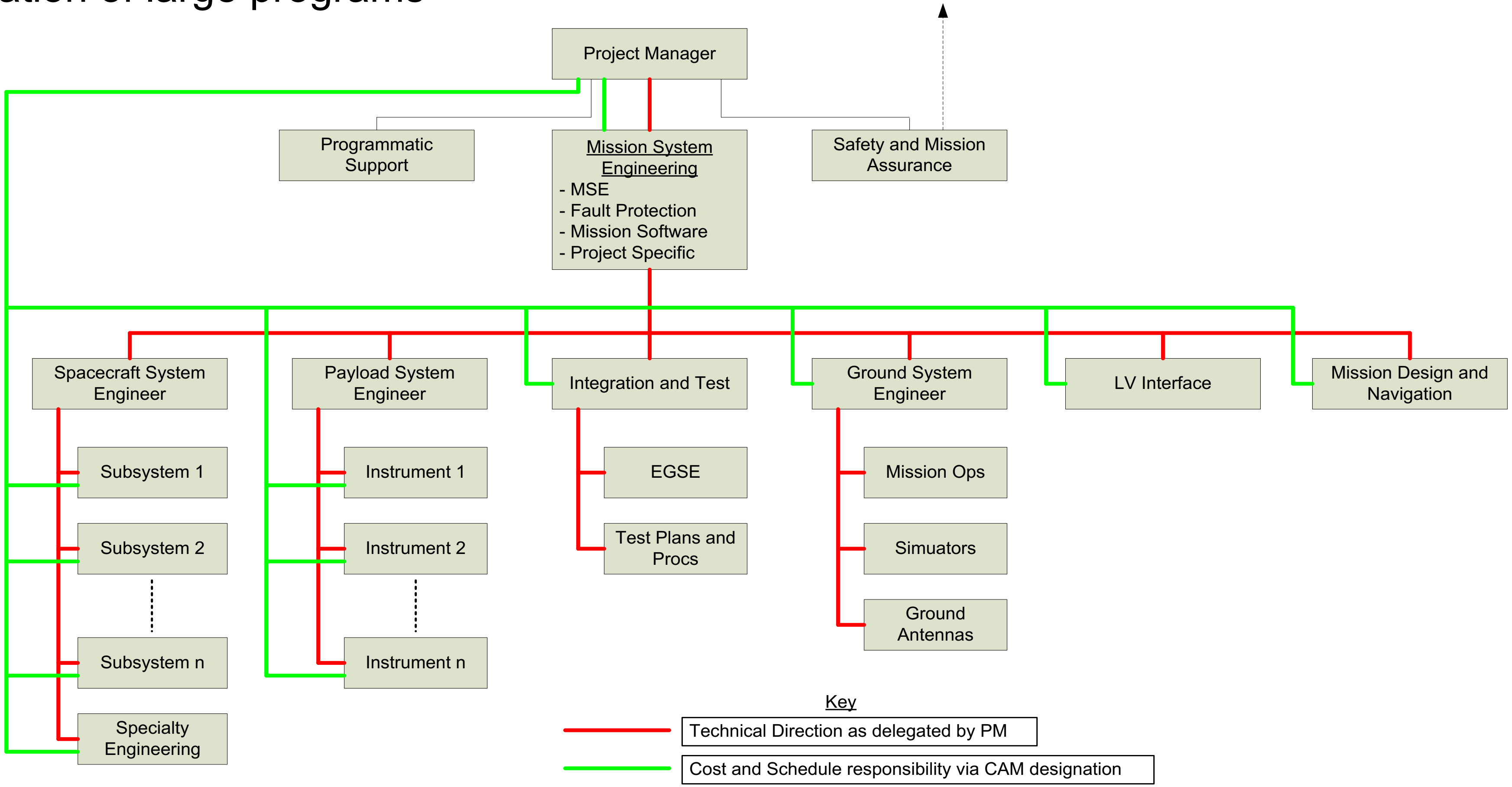
Agenda

- **Overview of SE at APL**
- Titan Overview
- Conception of Dragonfly
- Innovation, not Invention
- Getting to the Surface
- Designing for Titan
- Leveraging Titan's Environment
- Learning to Fly
- Surface ConOps
- It Takes a Village

Roles and Responsibilities – The Many Layers of Systems Engineering

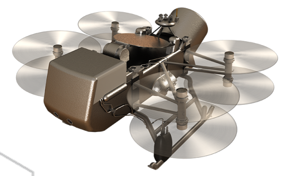


SE is the only reliable and traceable means sanctioned by the aerospace industry to manage the development and implementation of large programs



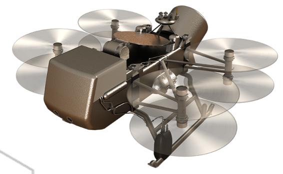
Typical large project organizational physical structure showing both technical and programmatic lines of authority

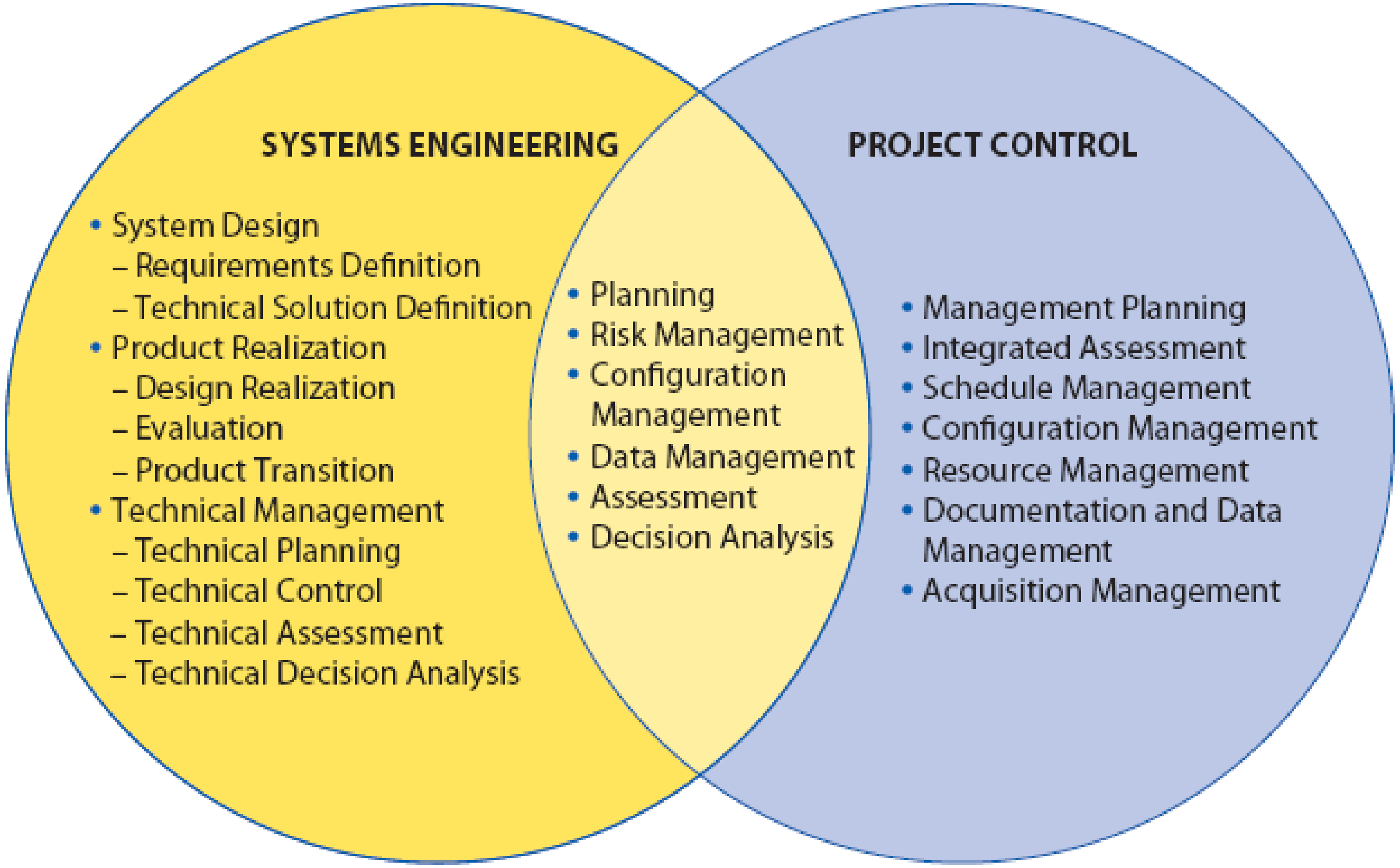
Systems Engineering Team



- APL utilizes a distributed systems engineering approach
  - Documented in our Quality Management System (QMS)
- Mission Systems Engineer (MSE)
- Segment System Engineers for each of the major mission segments
  - Spacecraft Systems Engineer (SSE)
  - Payload Systems Engineer (PSE)
  - Ground System Lead Engineer (GSLE)
  - Mission Operations Manager (MOM)
  - Payload Operations Manager (POM)
  - Launch Vehicle Lead Engineer (LVLE)
- Integration and Test Engineer
- Mission System Software Engineer (MSSE)
- Mission [Trajectory] Designer
- Fault Management Engineer
- System Assurance Manager (SAM)
- Reliability Engineering
- Specialty Engineering, such as EMI/EMC, contamination control, and radiation

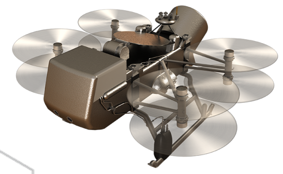
SE in Context of Overall Project Management





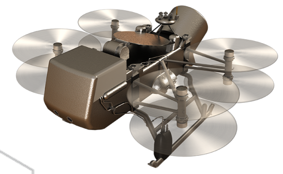
SE in context of overall project management

Systems Engineering Management – Technical Management and Oversight



- Systems engineering is as much a management job as a technical one
  - Technical management and oversight consume the greatest percentage of a system engineer’s time, yet it is nearly impossible to codify requirements for this aspect of the systems engineering function
- SE facilitates the flow of technical communication among the program team members
- System engineers must develop a team that is involved in system design by fostering open communication and demonstrating responsiveness to issues
  - Identify the many assumptions and design decisions that may affect other elements of the system
  - Ensure well-informed system trades and design decisions
- SE participates in elements of the detailed design when significant technical problems or issues arise
  - Controls system resources, functional reallocations, and modification of requirements, or relief from requirements
- The oversight role is performed through attendance at system and subsystem design meetings, review of documentation, and participation in design reviews

Systems Engineering Core Functions and Lifecycle Management

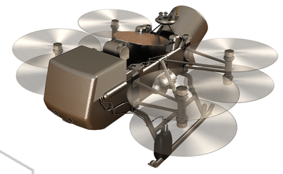


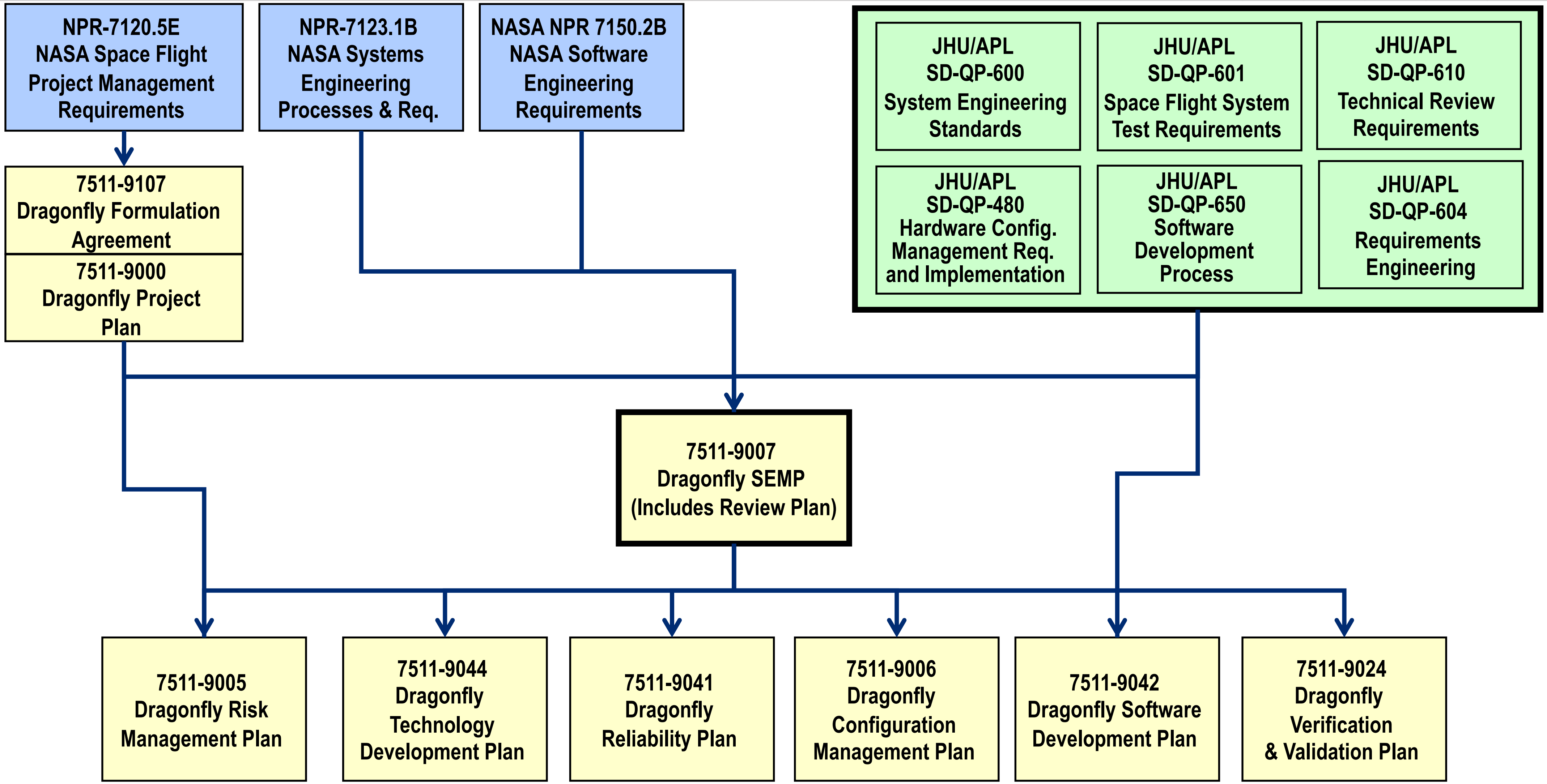
- Cradle-to-grave use of SE techniques through the mission lifecycle:
  - System architecture definition
  - Requirements development
  - Functional and physical descriptions
  - Implementation
  - Verification and validation
  - Operations

- Key SE functions are executed through specific disciplines and activities:
  - Requirements Engineering
  - Trade Studies
  - Interface Identification and Control
  - Baseline Identification and Control
  - Change and Product Control
  - Technical Performance Metrics
  - Requirements Verification and Testing

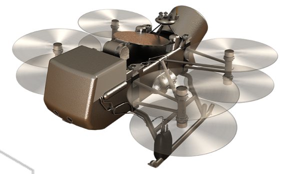
- Fundamentally, this is the application of technical management to control project baseline and technical resources

Dragonfly Technical Planning Document Tree

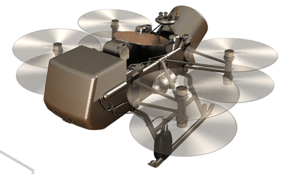




Dragonfly Systems Engineering Management Plan Contents



System Specification



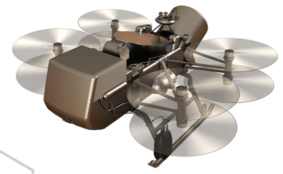
- SE Team is responsible for managing the design process
  - Need to ensure the design is captured and all project members are working from a common understanding

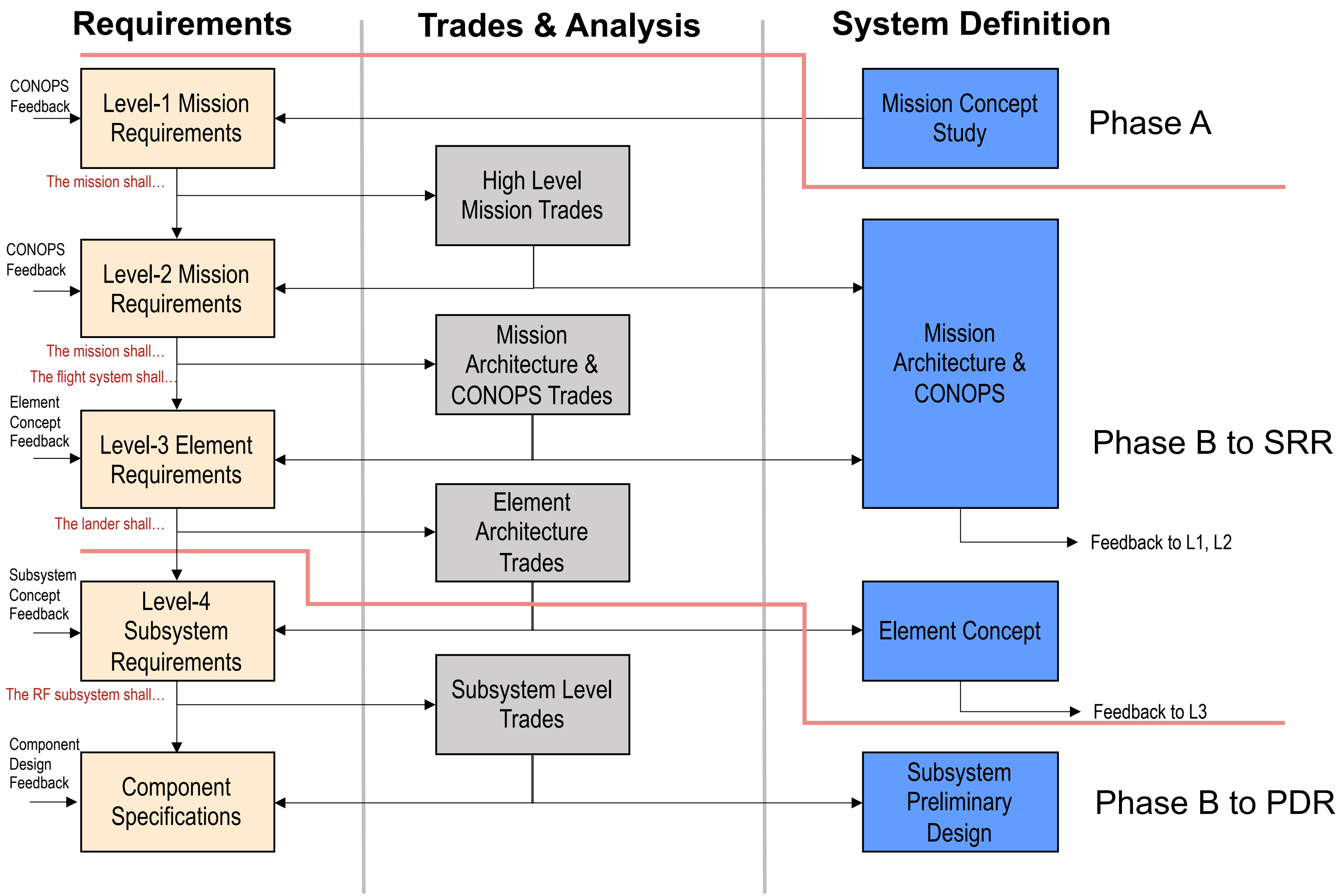
- Start with requirements definition and flow down

- Systems Architecture (or concept)
  - Not a traditional SE deliverable
  - Early project efforts focus on defining an architecture
  - Effective means for understanding interfaces, risks, and necessary controls
  - Evolves from early trades on system constraints, risk posture, fault tolerance, preexisting elements, concept of operations, cost, schedule, etc.

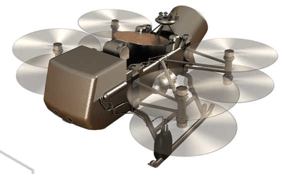
- Baseline captures the mission-level design description
  - Each major review and the corresponding actions represent a snapshot of the design baseline

Requirements and Design Process



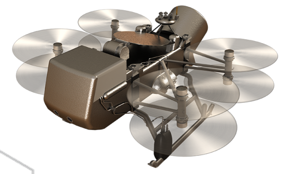


Trade Study Approval Process



Approval Level	Trade Result or Change Implications	Responsible for Completion	Approval (Concurrence)
1	Affects L1 or L2 requirements, cost or schedule impact exceeds reserves, new technologies below TRL-6 are introduced, or mission risk could be significantly impacted.	Project Science/MSE	Principal Investigator, PM (NASA if PIMMC or PLRA impacted)
2	Affects L3 requirements, cross element boundaries (L2 interfaces), system or element margins, fundamental change to the element level design architecture or technologies used, or has a medium impact on mission risk. - Level-1,2 requirements unaffected - Launch readiness date unaffected - Cost and schedule impacts are within planned reserves. - No new technologies introduced below TRL-6	MSE/FSE	Flight System / Payload Manager, Project Manager (Principal Investigator)
3	Affects L4 requirements, cross multiple subsystems within a system element, fundamental change to a subsystem design architecture or technologies used, or has a medium impact level on element level risk. - Level-2 requirements unaffected - Other elements unaffected - Cost and schedule contained within element allocation	Element Level Systems Engineer • LSE / CS Lead / EDL Lead • PSE • MOM • SciOps • MD Lead • Test Env. Engineer	MSE, FSE (Flight System / Payload Manager)
4	Trades that fall within a particular subsystem or instrument - Trade does not affect other subsystems or instruments - All L4 requirements met - Cost and schedule contained within subsystem/instrument allocation - Low risk impact	Subsystem / Instrument Lead Engineer	Element Level Systems Engineer (MSE, FSE, PSE, PM, FS/Pyld Manager)

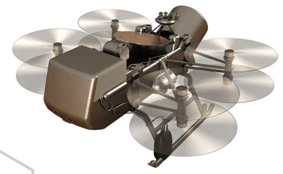
Mission Level Trade Studies



- Majority of mission trades were completed during the proposal and competitive Phase A Concept Study.
- The proposed architecture was accepted by NASA, constituting KDP-B, with the following directed changes:
  - Launch in 2027 on an high-energy ELV with a 5 m fairing
  - Other identified weaknesses are being addressed through the design process and will be closed by PDR

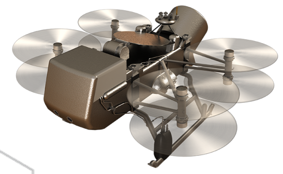
#	Trade(s)	Result
M1	4.5-meter Aeroshell Diameter	Grew aeroshell from 3.75 m to 4.5 m; increases key margins available to lander element
M2	Battery Voltage and Capacity	Use 100-V 24s1P Battery over CSR’s 70-V 18s1P Battery
M3	Lander MGA	Replace 4 LGAs with a gimbaled MGA
M4	Forward Science Camera FOV	Retained CSR baseline of forward camera FOV rather than using PanCam design
M5	Timekeeping Architecture	Spacecraft clock in the Critical Bus Hibernation Controller (CBHC) and the redundant (backup) clock in the backup Hibernation Controller

Mass and Power Management



- Process is consistent with standard APL practices and what was performed on past APL missions
- Project tracks mass and power at a component-level, and reports at the system-level on a monthly basis
- Margins maintained as flight system and instrument components grew in Phase A
- Phase B, MEVs defined and allocated to instruments and spacecraft subsystems
  - Contingencies updated based on maturity
  - Any growth worked off of contingencies and margins
  - Managed in requirements and through MEL/PEL
- Unallocated margin is held at the project level to address unknowns
  - If MEV is exceeded, any change will be managed a the project level and modify the requirement if deemed appropriate

Technical Performance Measures Heading into PDR



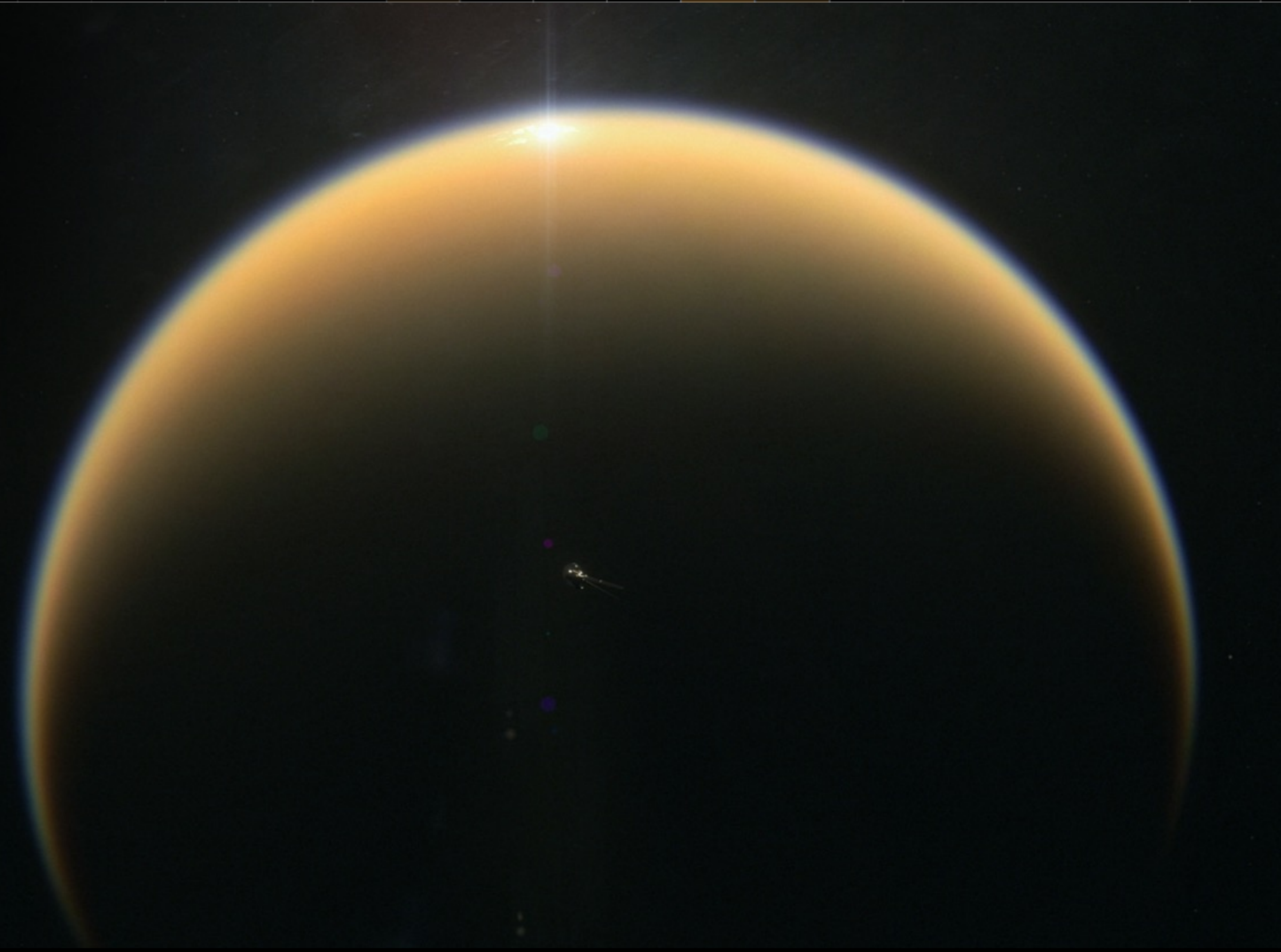
- Flight System Dry Mass Margin
  - Target ≥ 25% total margin at spacecraft level
- EOL Power Margin
  - Target ≥ 25% total margin at spacecraft level
- Uplink Margin – 3 dB maintained through launch
- Downlink Margin – 3 dB maintained through launch
- Data Rate Margin ≥ 20%
  - Data return margin
  - Data rate margin to recorder
  - Recorder storage margin
- Processor Throughput Margin ≥ 50%
- Critical Processor Memory Margin ≥ 50%
- Critical Non-Volatile Memory Margin ≥ 50%
- Data Bus Throughput Margin ≥ 50%
- Delta-V/Propellant Margin
  - ΔV Budget carries both deterministic and statistical maneuvers, as well as attitude control allocation
  - Carry an additional 10% margin on capability

Agenda

- Overview of SE at APL
- **Titan Overview**
- Conception of Dragonfly
- Innovation, not Invention
- Getting to the Surface
- Designing for Titan
- Leveraging Titan's Environment
- Learning to Fly
- Surface ConOps
- It Takes a Village

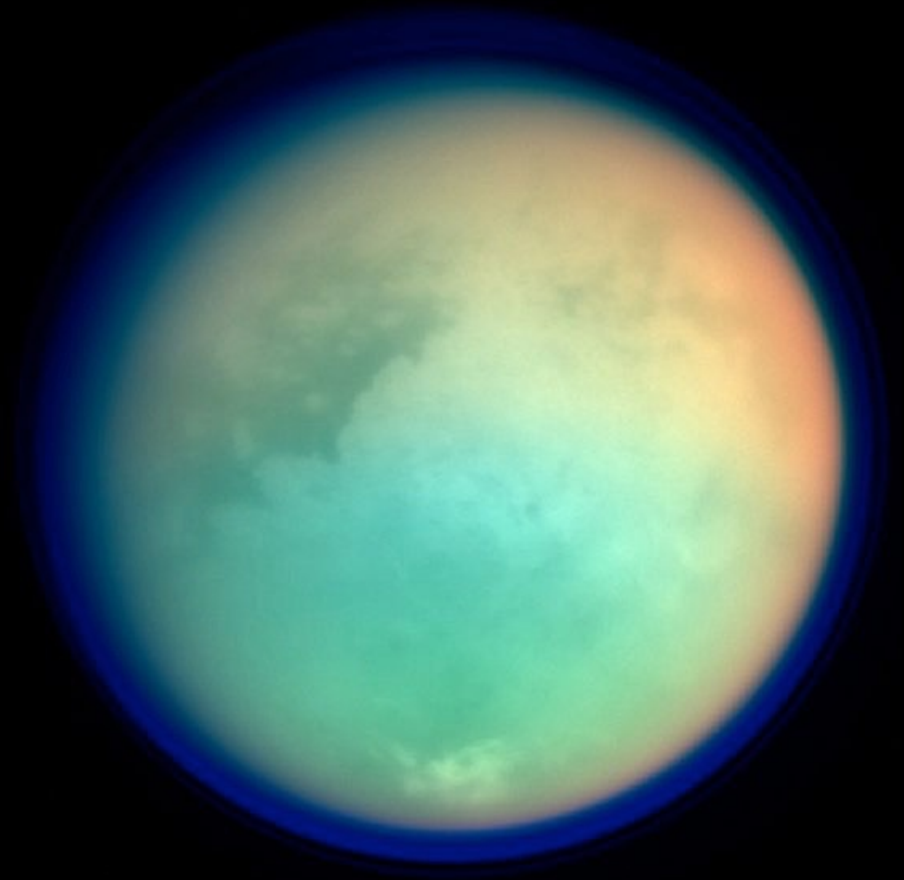
Unique and Compelling Scientific Opportunity

- We do not know how life came to form on Earth and cannot go back to study our own prebiotic history.
- Places elsewhere in our Solar System provide pieces to the puzzle of the chemical processes that led to life.
- Titan is the most like the early Earth and holds keys to understanding our chemical origins.



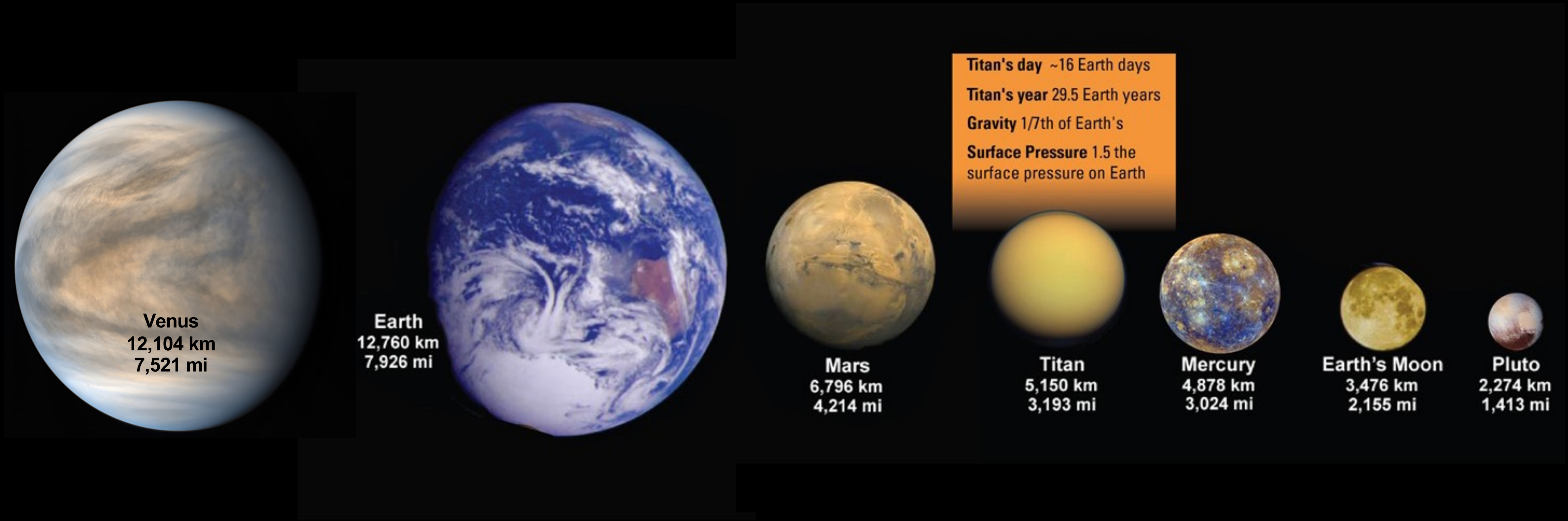
Titan

- Diameter = 5150 km
- Surface gravity = 1.35 m/s2 = 0.14 g
  - 14% of gravity at Earth’s surface
  - 83% of gravity at Moon’s surface
- Surface pressure = 1.5 bar
  - 1.5× pressure at Earth's surface
- Surface temperature = 94 K = –290°F
  - Bedrock composition = water ice



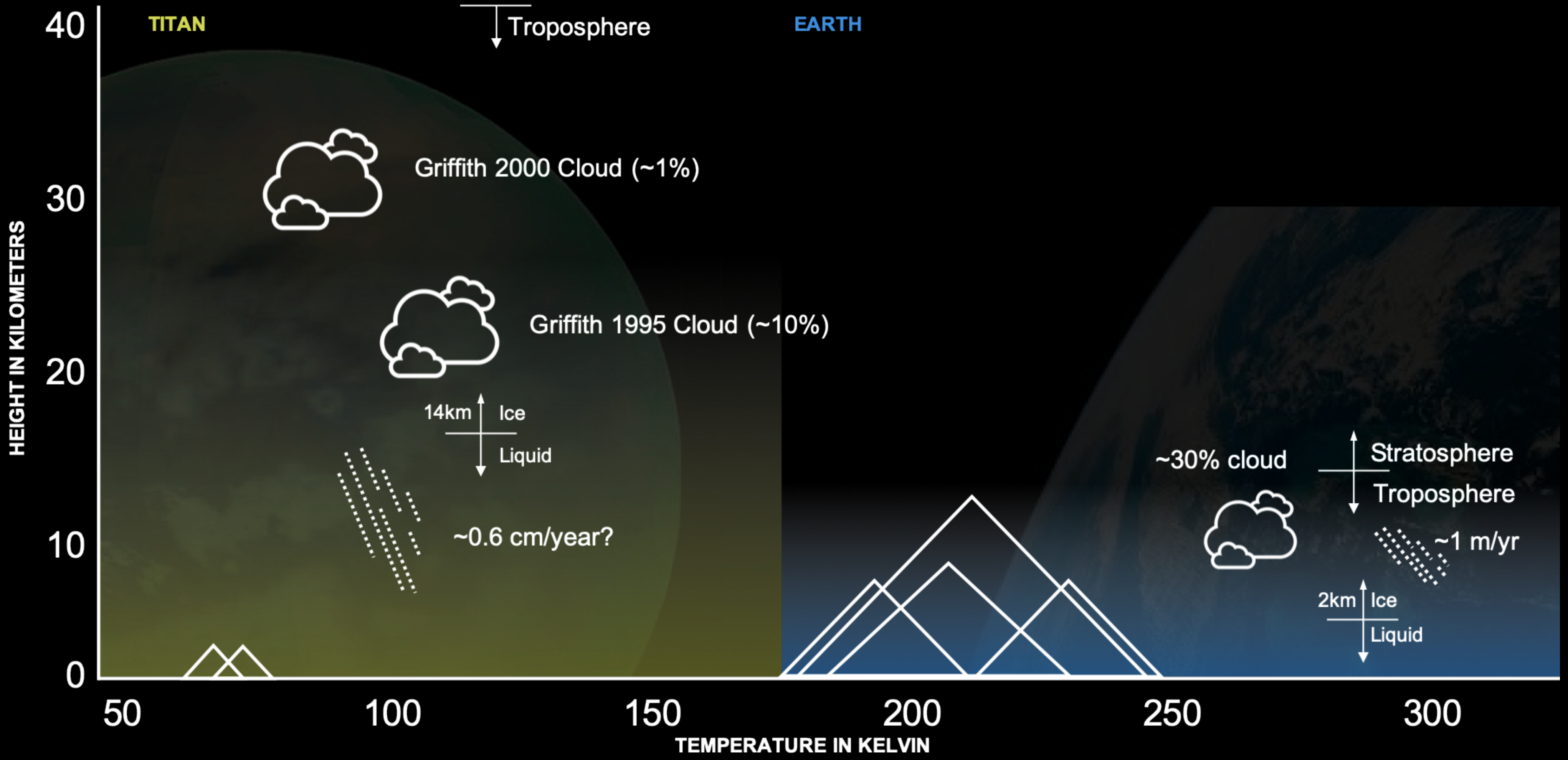
26 October 2004

Titan's Atmosphere is Denser than Earth's

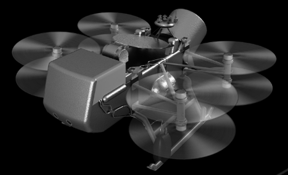


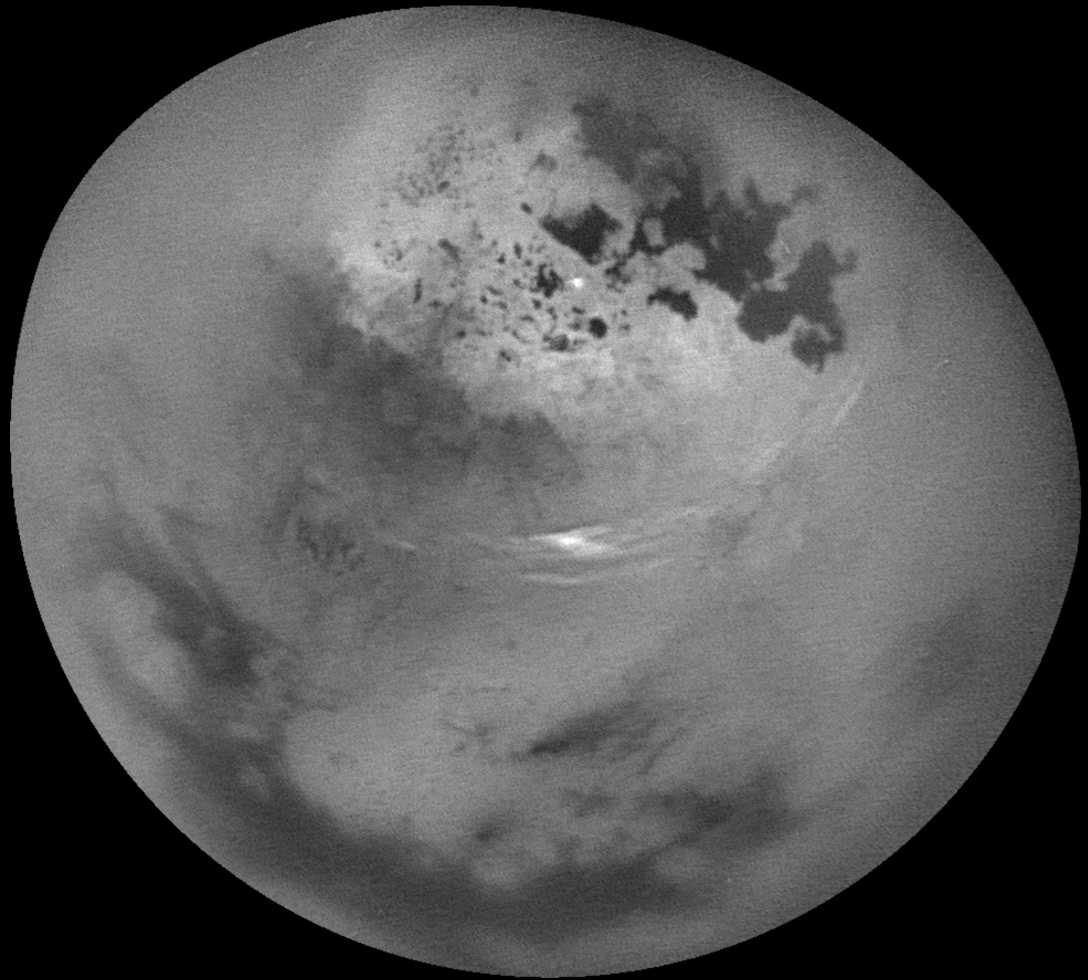
- 2nd highest surface pressure of all solid bodies with atmospheres
- 1.5× pressure at Earth's surface

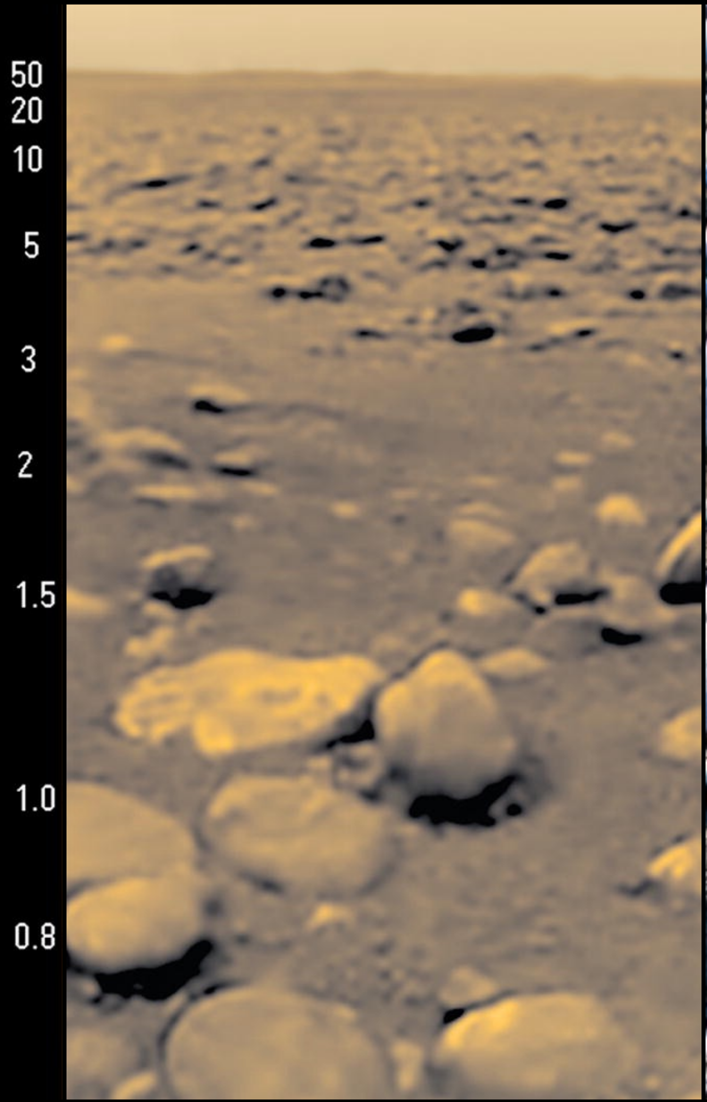
Extended Atmosphere

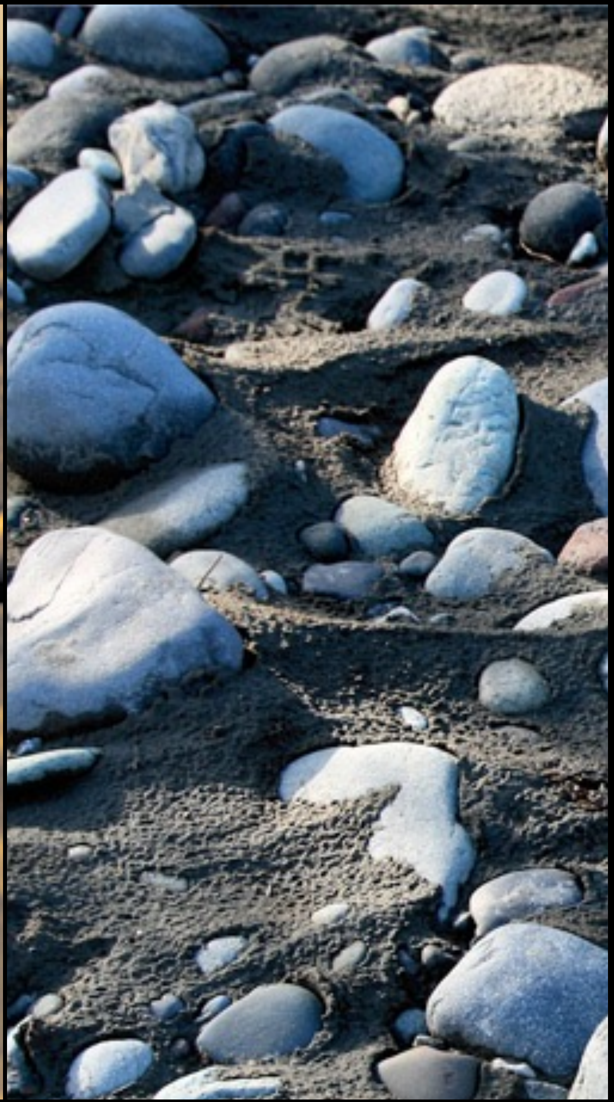


Titan’s Surface is Modified by **Earth-like Processes**

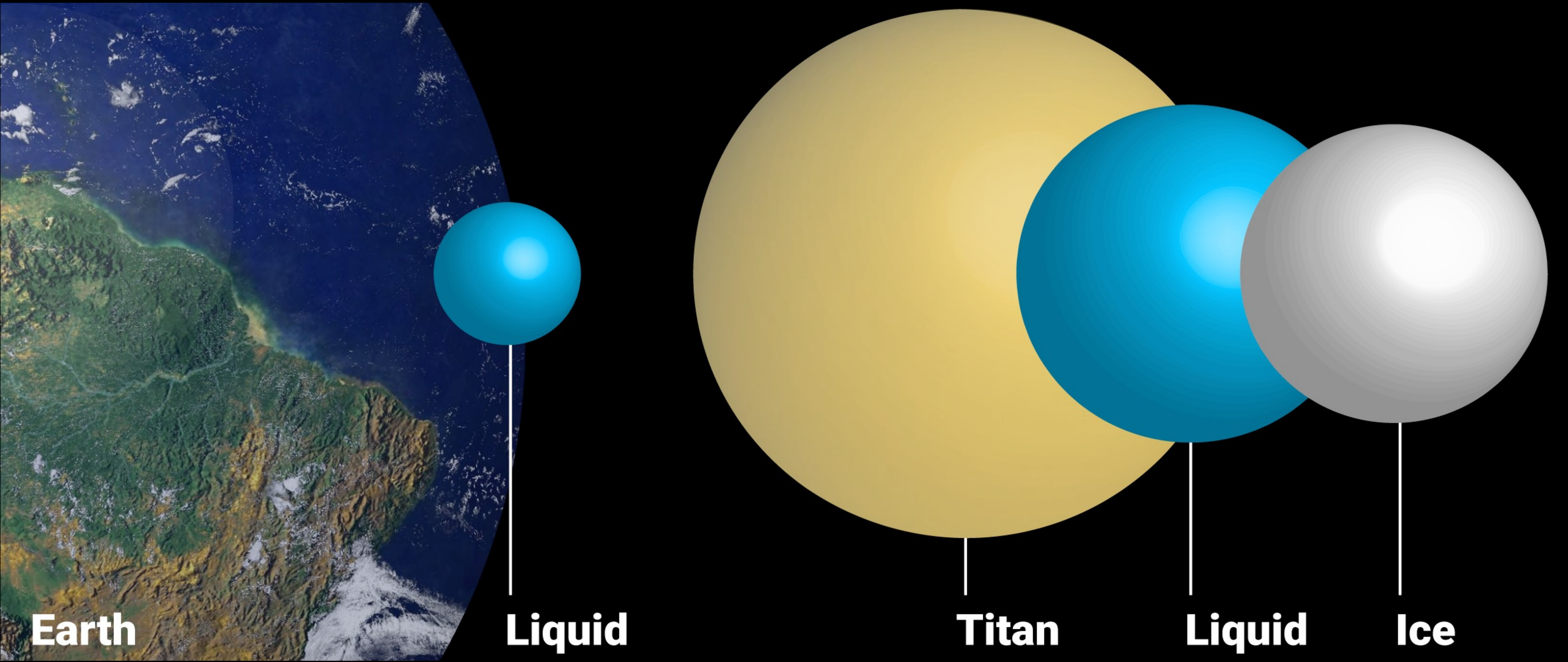




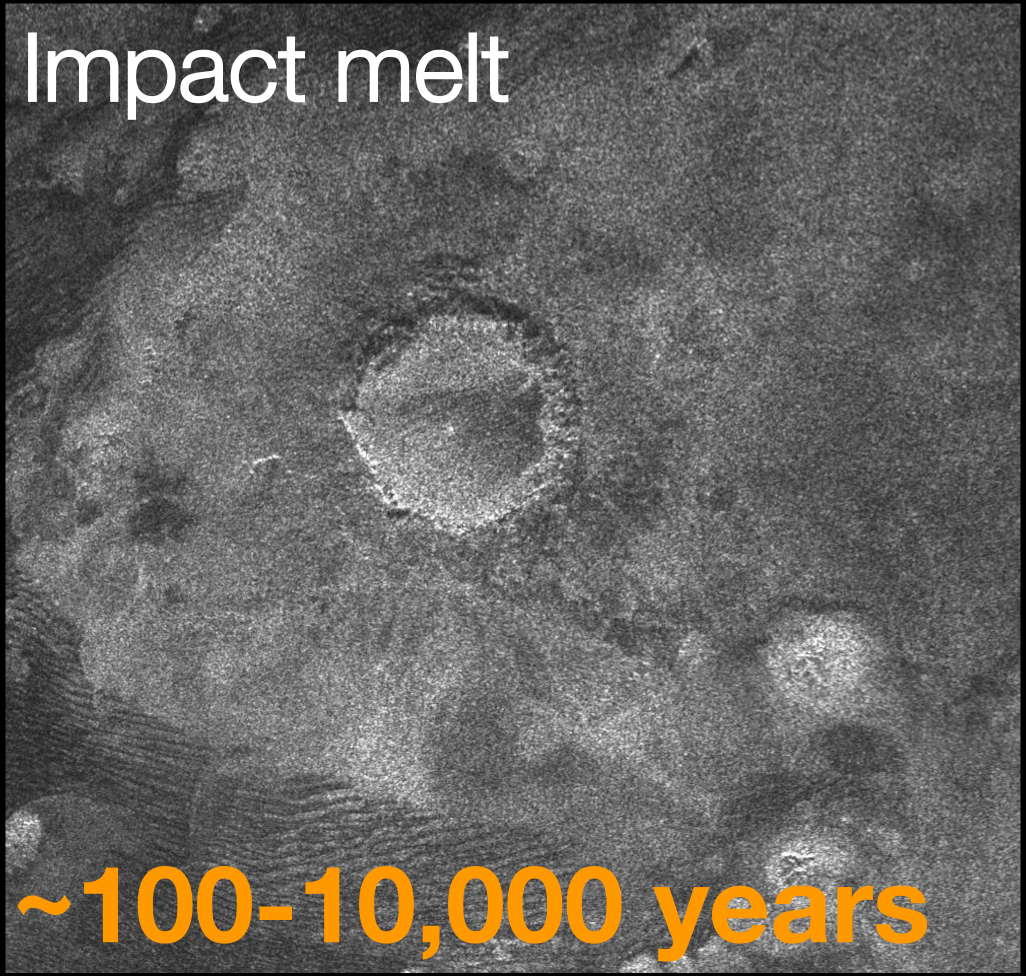




Titan has a Subsurface Ocean of Liquid Water

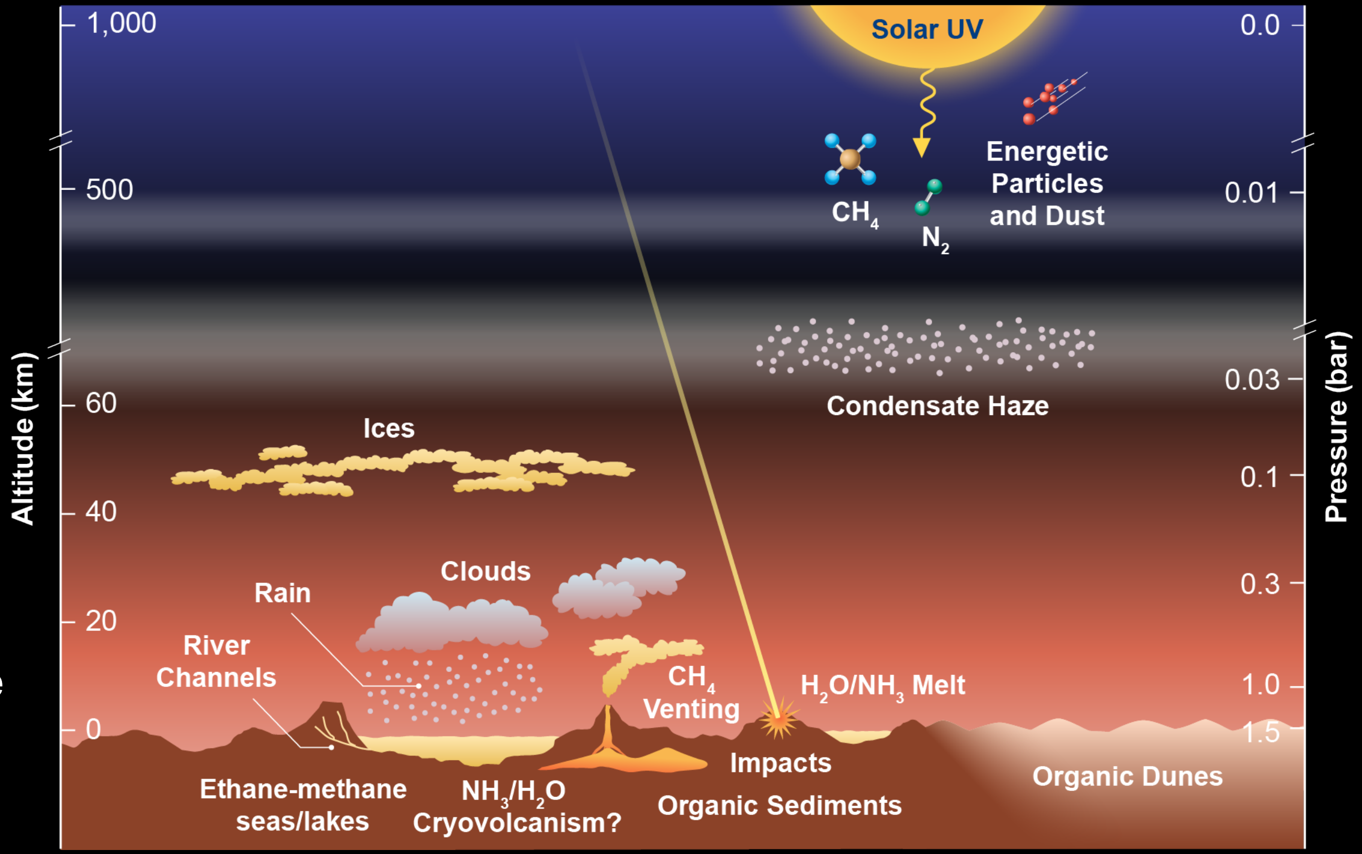


Titan's Surface has Hosted Transient Liquid Water Environments



Key Ingredients Necessary for Life

- Energy
  - Sunlight, photochemistry
- Organic material
  - Abundant complex organics
- *Two* liquids
  - Water
    - available at the surface in Titan's past
    - interior ocean
  - Methane
    - active methane cycle like Earth's water cycle
    - liquid methane could support development of alternate biological systems



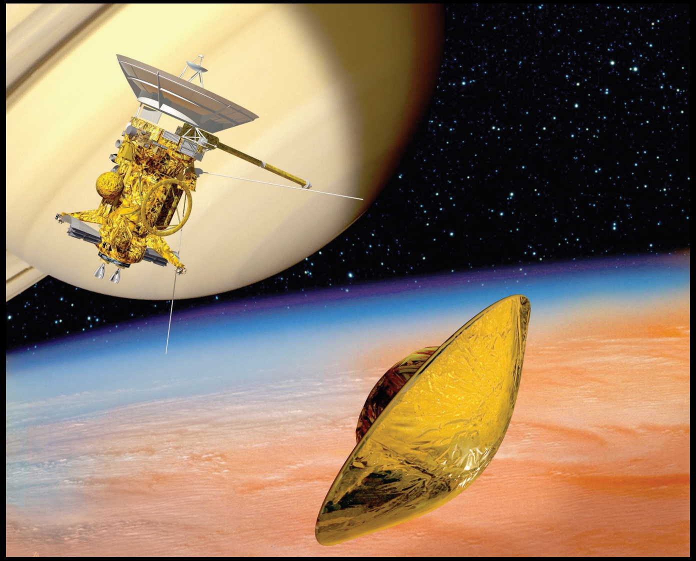
On Titan alone, can we study prebiotic chemistry in the full context of a planetary environment and Earth-like surface processes.

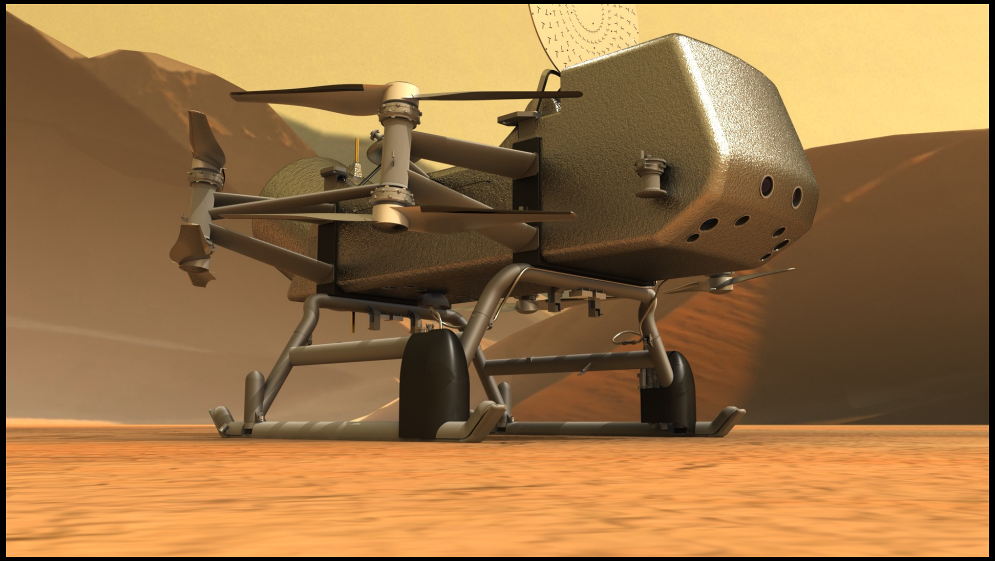
Titan Offers the Next Step to Answer Fundamental Questions

What makes a planet or moon habitable?

What chemical processes led to the development of life?

Has life developed elsewhere in our solar system?

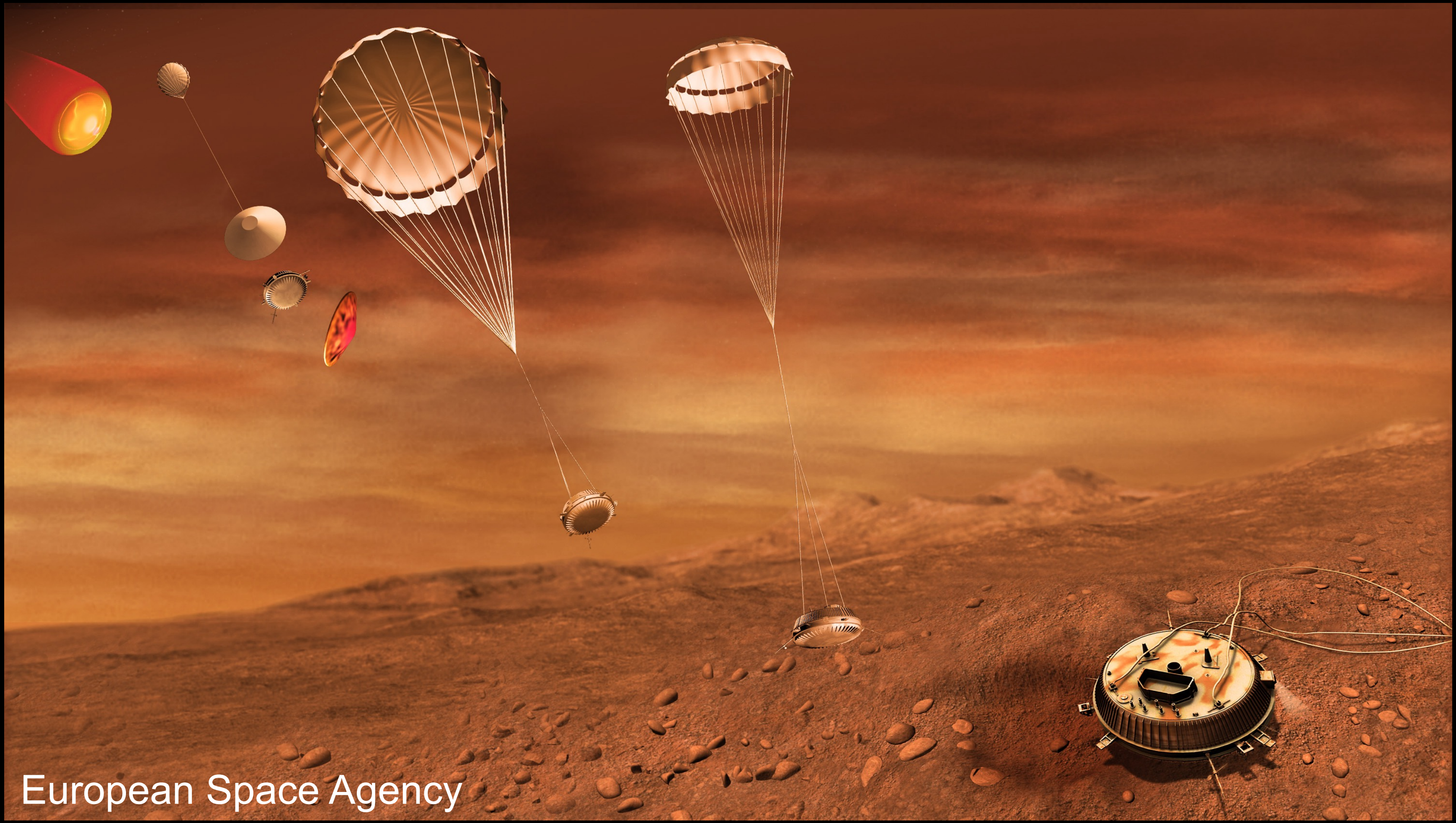


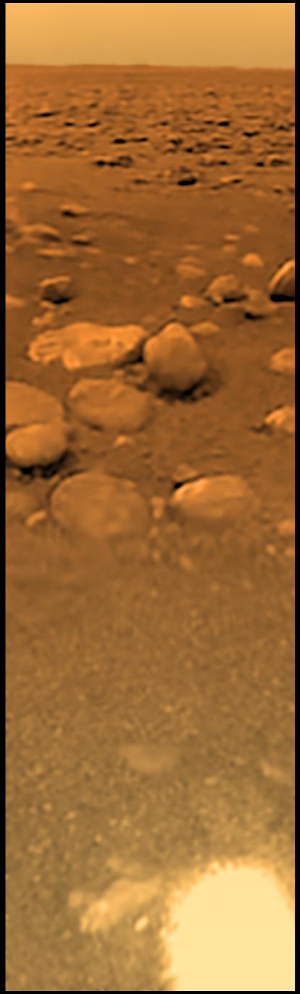


Agenda

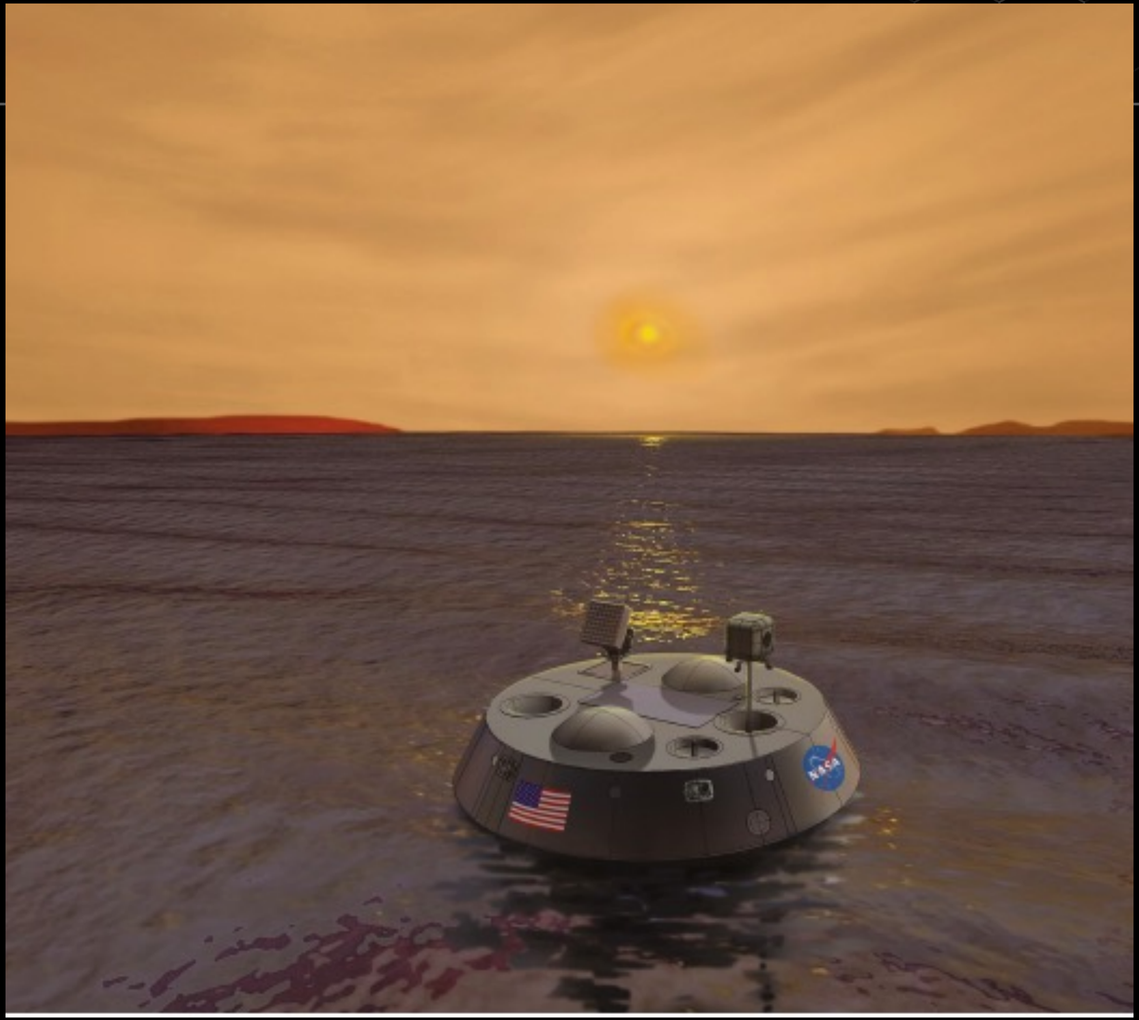
- Overview of SE at APL
- Titan Overview
- **Conception of Dragonfly**
- Innovation, not Invention
- Getting to the Surface
- Designing for Titan
- Leveraging Titan's Environment
- Learning to Fly
- Surface ConOps
- It Takes a Village

Huygens Atmospheric Descent, 2005

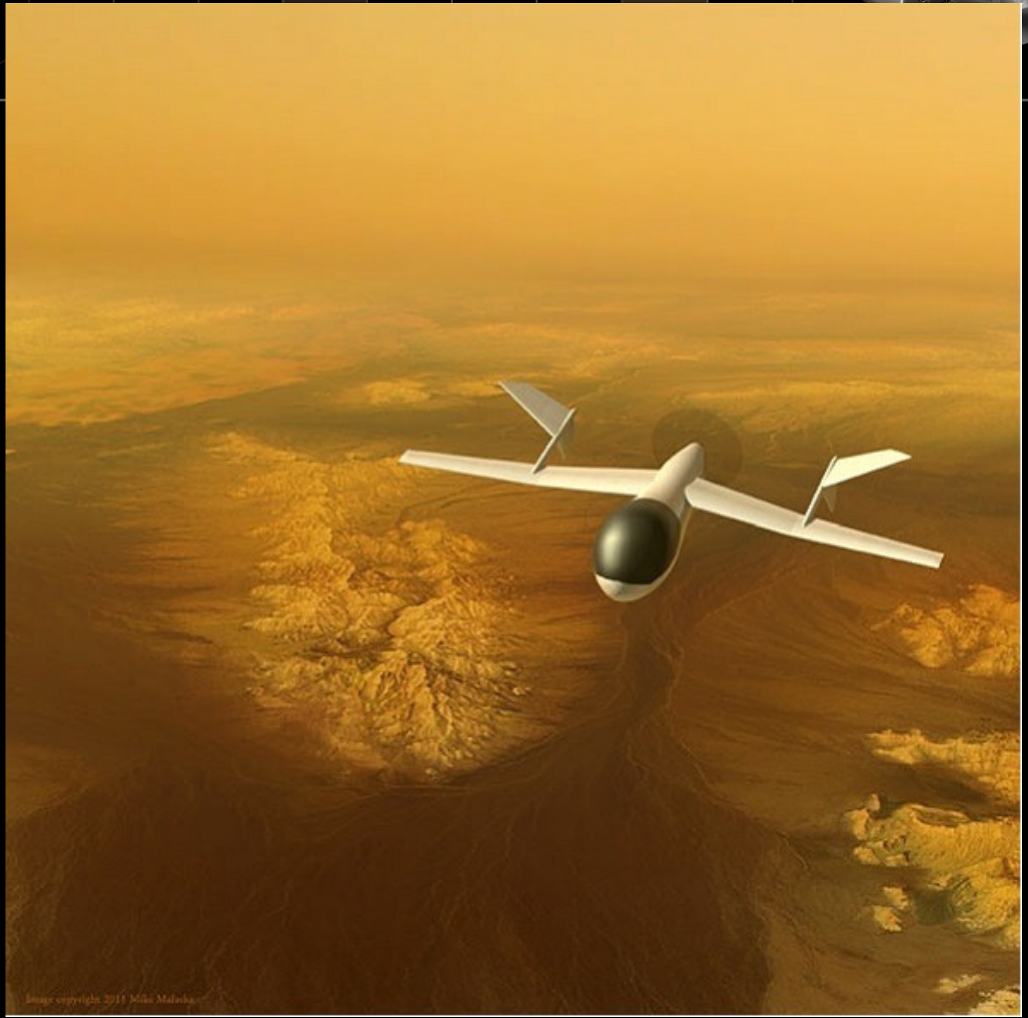




Ideas 2009-2012

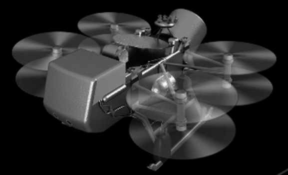


Titan Mare Explorer capsule (Discovery Phase A)
Relied on DTE Telecom in 2019-2024 N. Summer



AVIATR Airplane Concept. Relied on power/weight ratio of ASRG Stirling Generator

Titan Environment offers Transformative Aerial Mobility

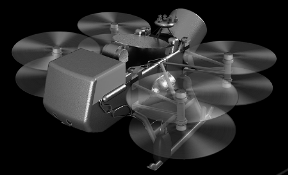


Rotorcraft advocated 20 years ago by Lorenz*. Can hover with 38x less power than Earth !

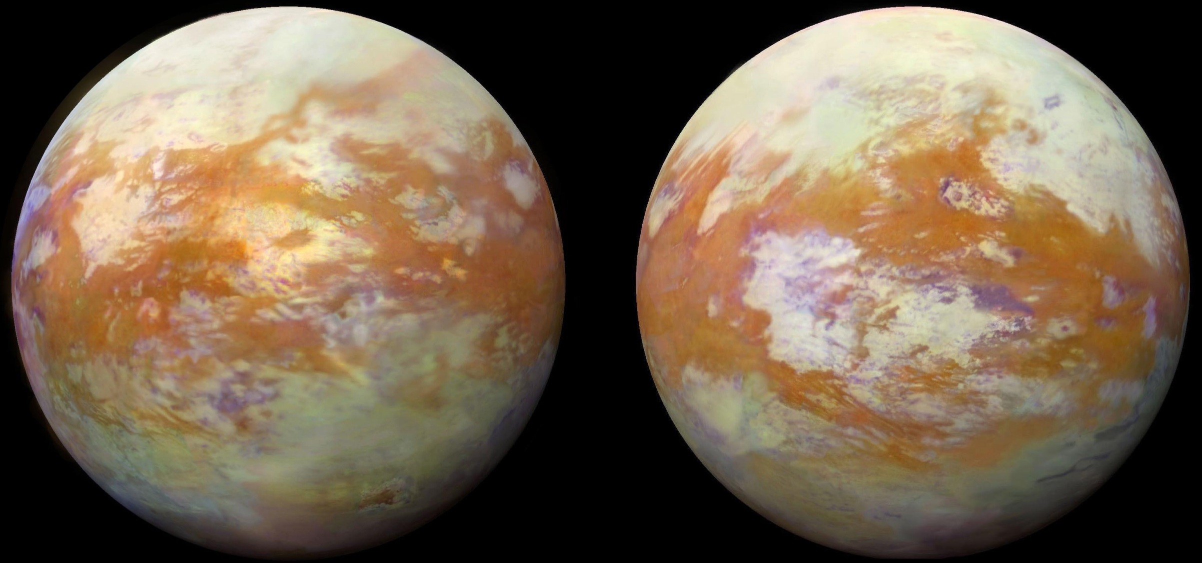
*and independently by L. Young (NASA Ames)

Low T gives lower viscosity (higher Reynolds number.) Rotor aerofoil section can be similar to terrestrial wind turbines (Sound speed lower : tip Mach number constraint)

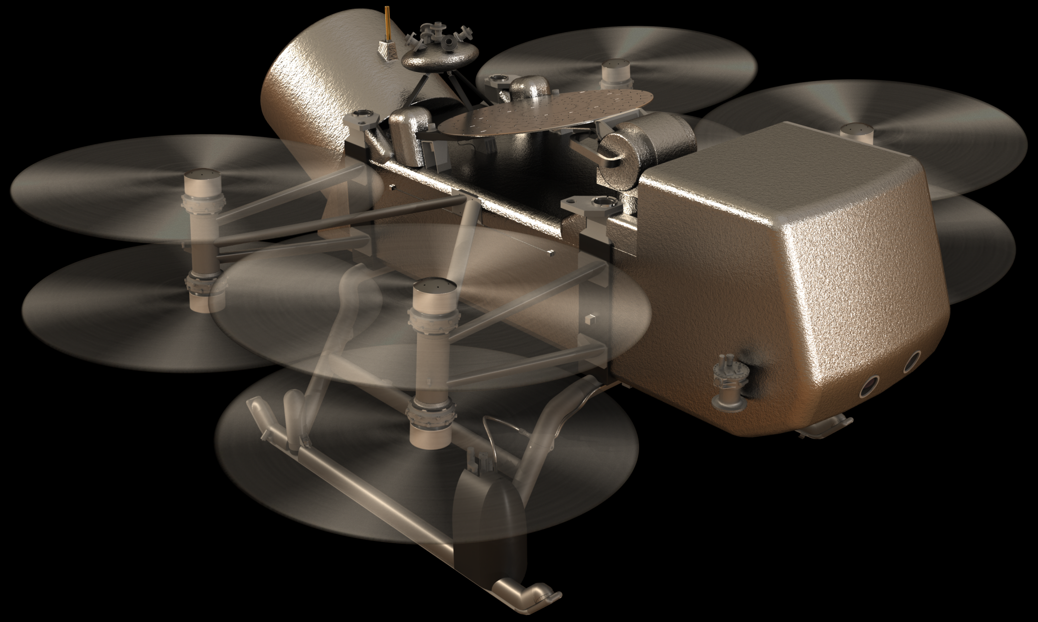
Lander with Aerial Mobility Enables Wide-Ranging In Situ Exploration – Key for Science Measurements



- Cassini revealed where to look for answers
  - Diverse surface materials and environments
  - Earth-like variety of geologic processes
  - Science challenge is to get instruments to multiple sites to sample materials and measure composition



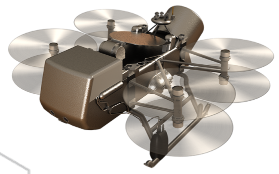
- Heavier-than-air mobility highly efficient at Titan
  - Atmospheric density 4x higher than Earth's reduces wing/rotor area required for lift
  - Gravity 1/7th of Earth's → reduces power required



Agenda

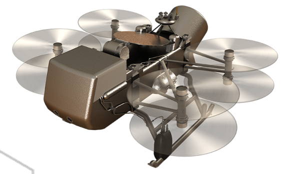
- Overview of SE at APL
- Titan Overview
- Conception of Dragonfly
- **Innovation, not Invention**
- Getting to the Surface
- Designing for Titan
- Leveraging Titan's Environment
- Learning to Fly
- Surface ConOps
- It Takes a Village

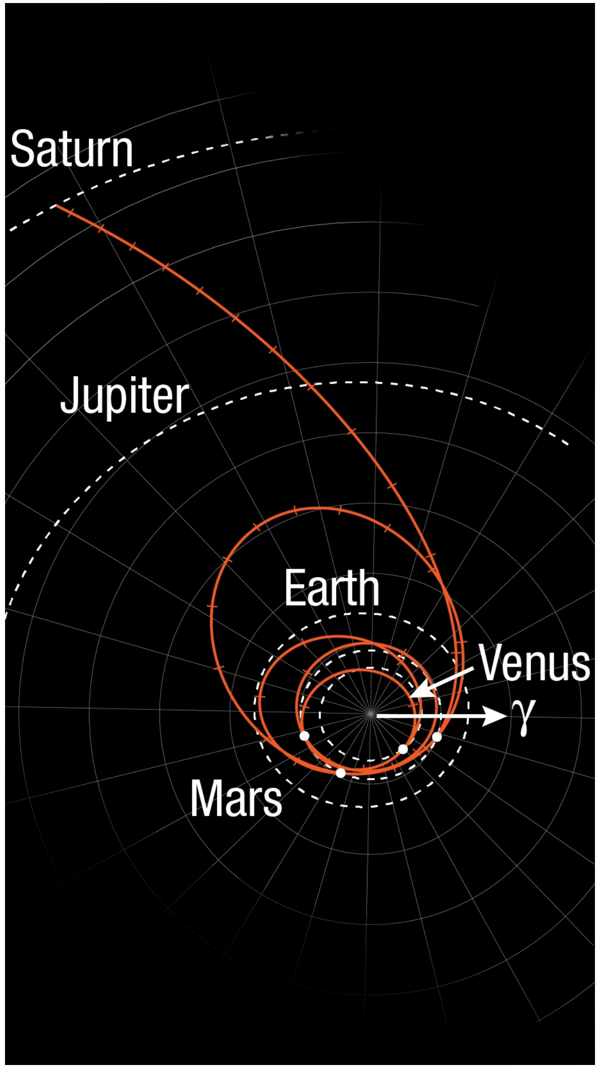
Fusing Established Technologies and Capabilities Across the *Dragonfly* Team

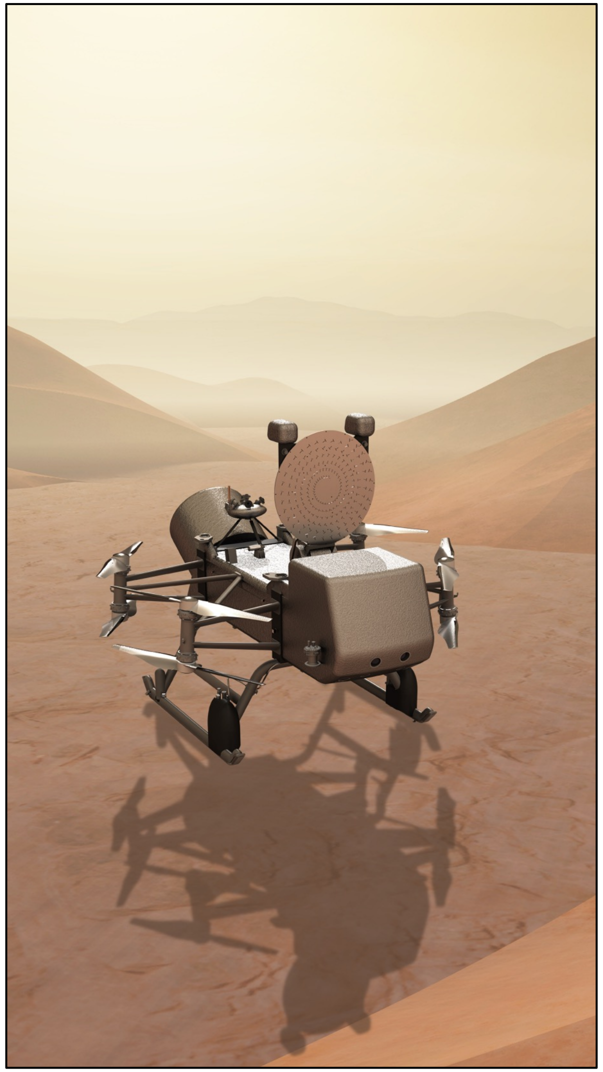


Innovation, not invention, enables *Dragonfly* to be successfully executed as a New Frontiers Class Mission

Dragonfly's Efficient Implementation Consists of Four Distinct Mission Phases

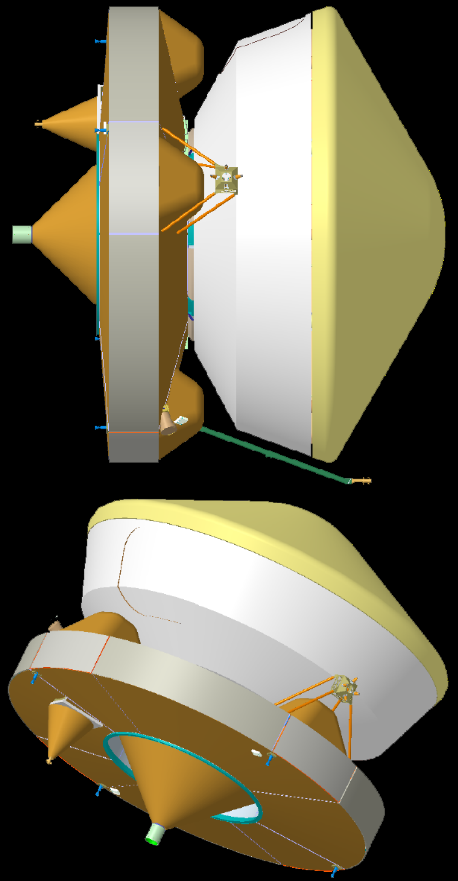




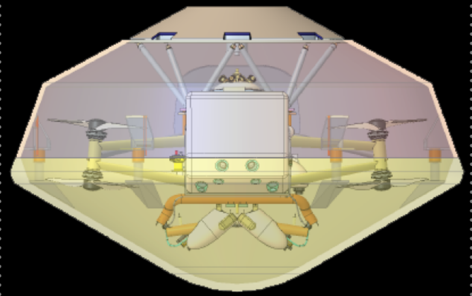


Mission Elements

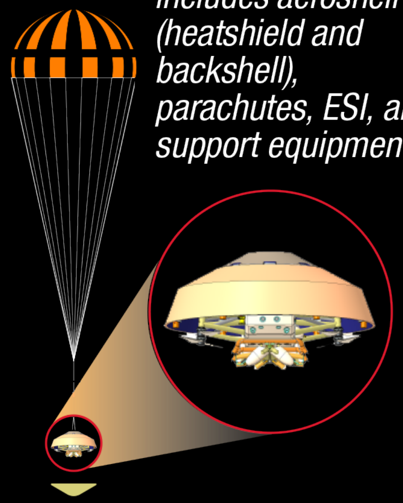
Spacecraft =
Cruise Stage + Entry Vehicle



Entry Vehicle =
EDL Assembly + Lander

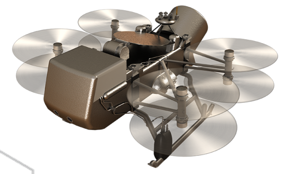


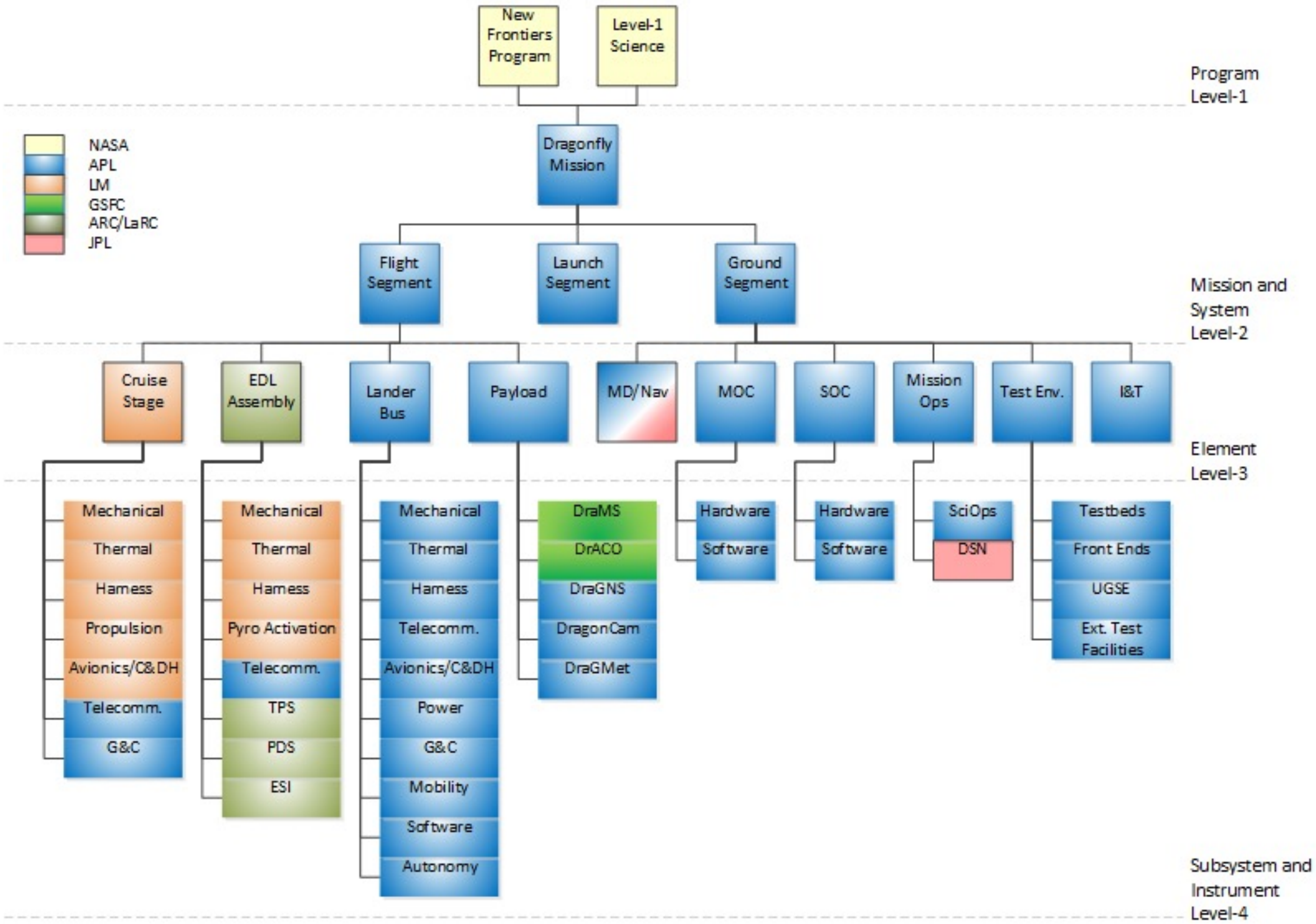
EDL assembly includes aeroshell (heatshield and backshell), parachutes, ESI, and support equipment.



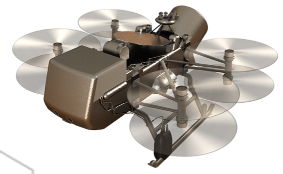
Rotorcraft Lander
Flight configuration with HGA stowed

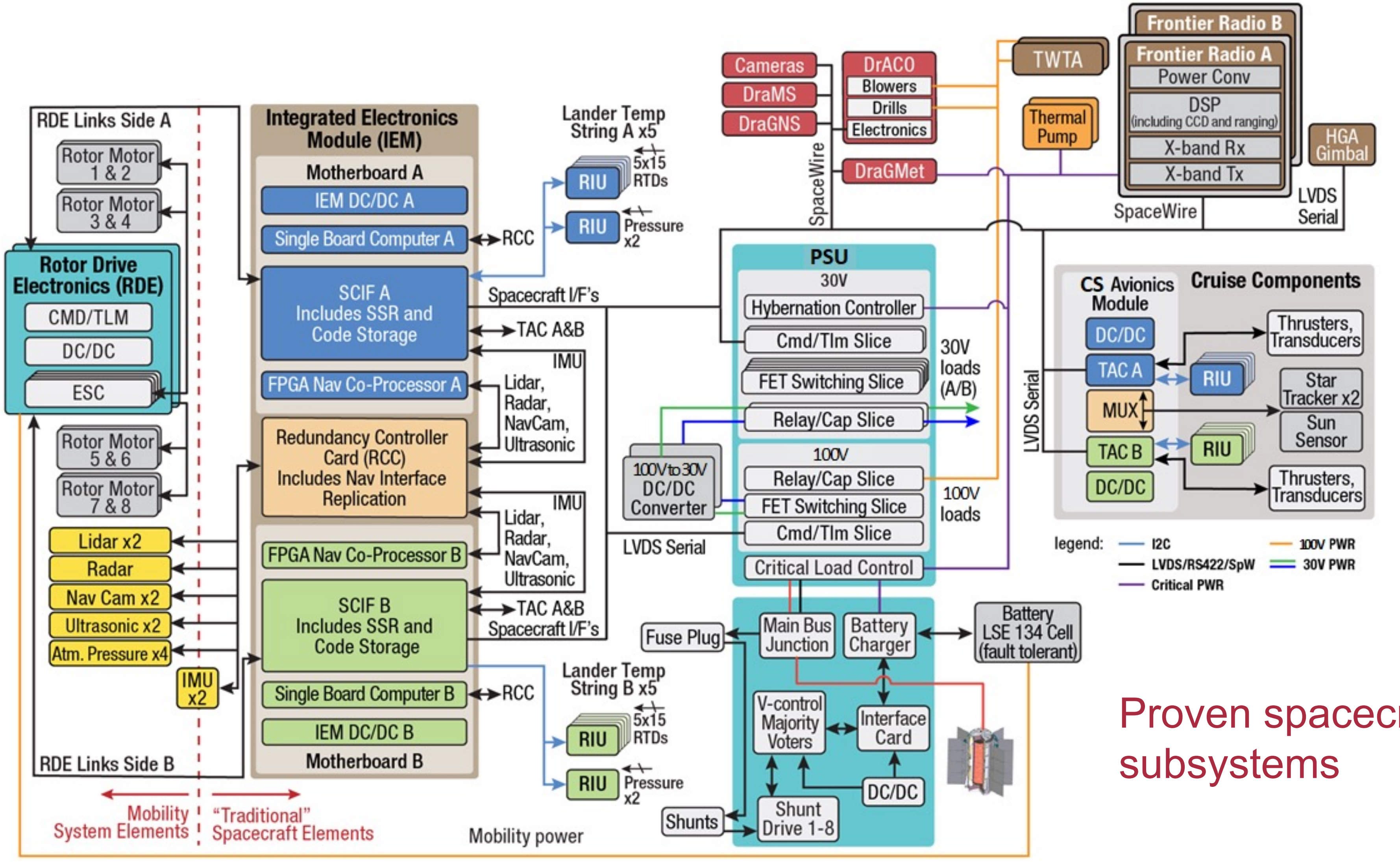
Dragonfly System Product Breakdown Structure





Innovative Surface Flight Capabilities Are Isolated in Single Subsystem





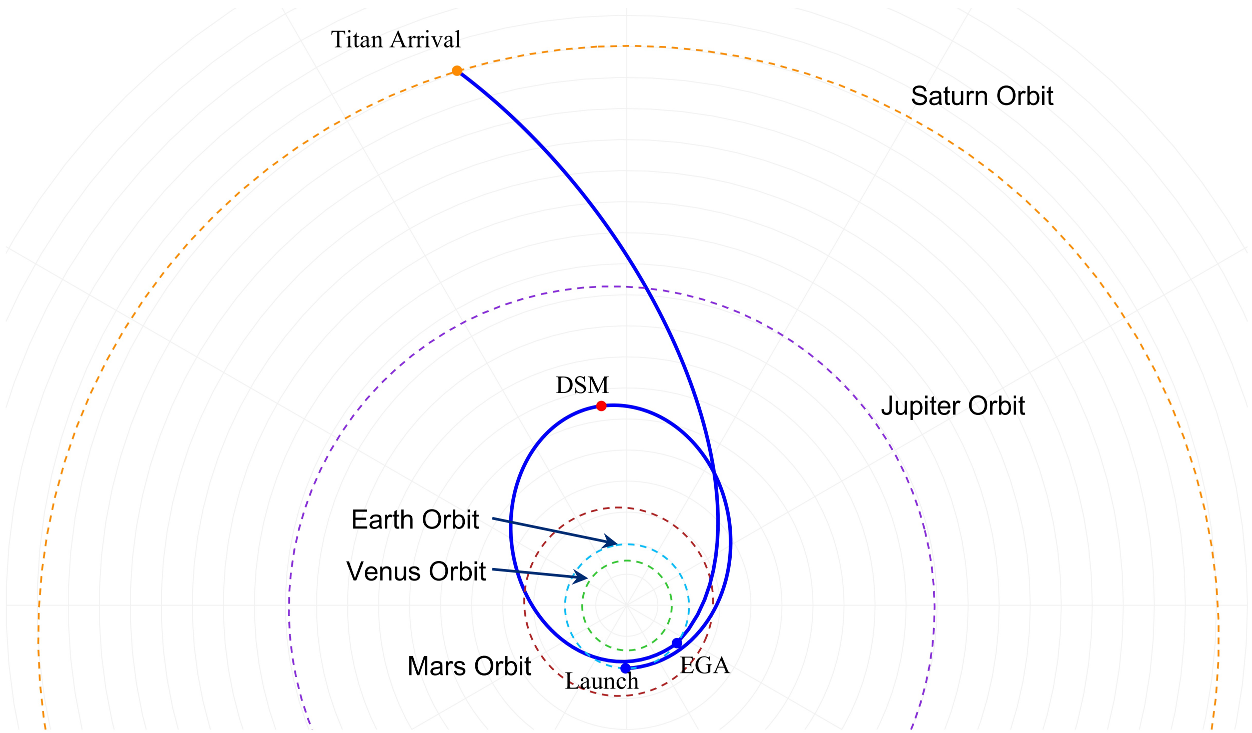
Proven spacecraft subsystems

Agenda

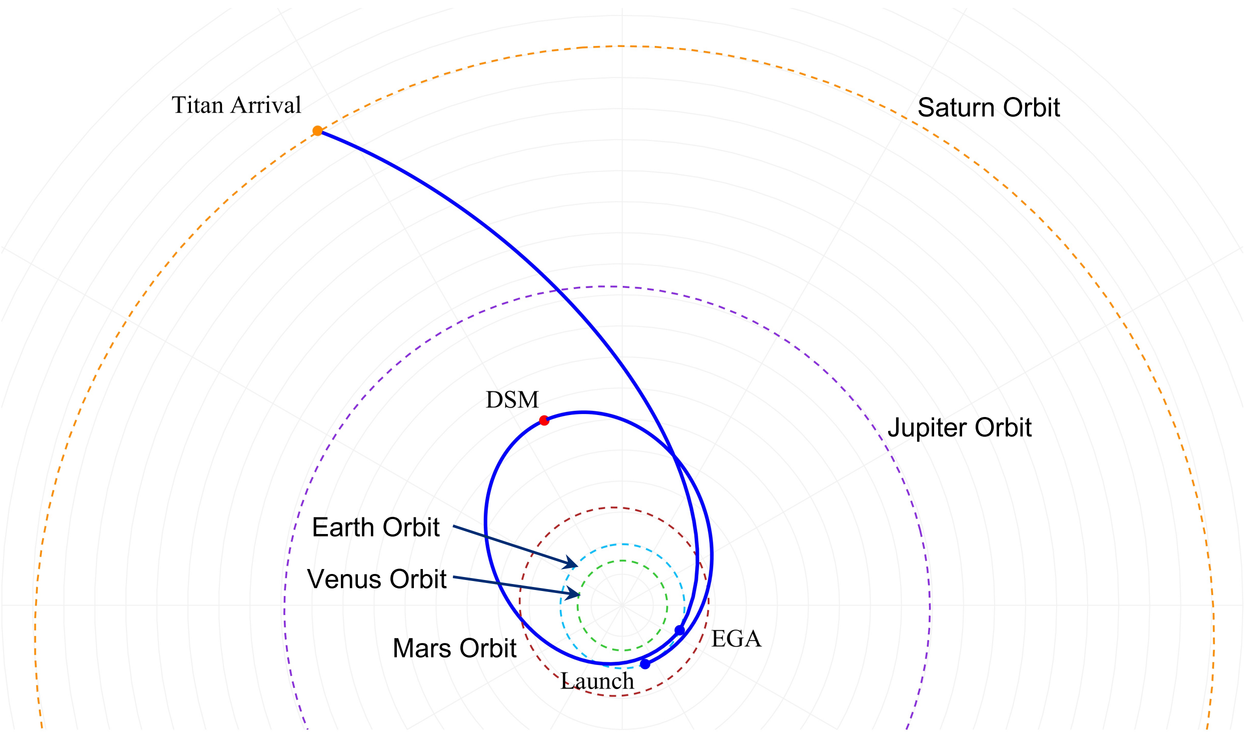
- Overview of SE at APL
- Titan Overview
- Conception of Dragonfly
- Innovation, not Invention
- **Getting to the Surface**
- Designing for Titan
- Leveraging Titan's Environment
- Learning to Fly
- Surface ConOps
- It Takes a Village

Heavy-Class Options (ΔV-EGA[3+])

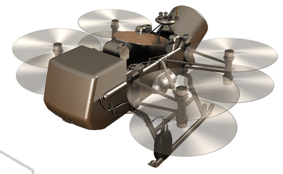
Baseline: 2027 ΔV-EGA



Backup: 2028 ΔV-EGA



Aimpoint Biasing of Earth Gravity Assist

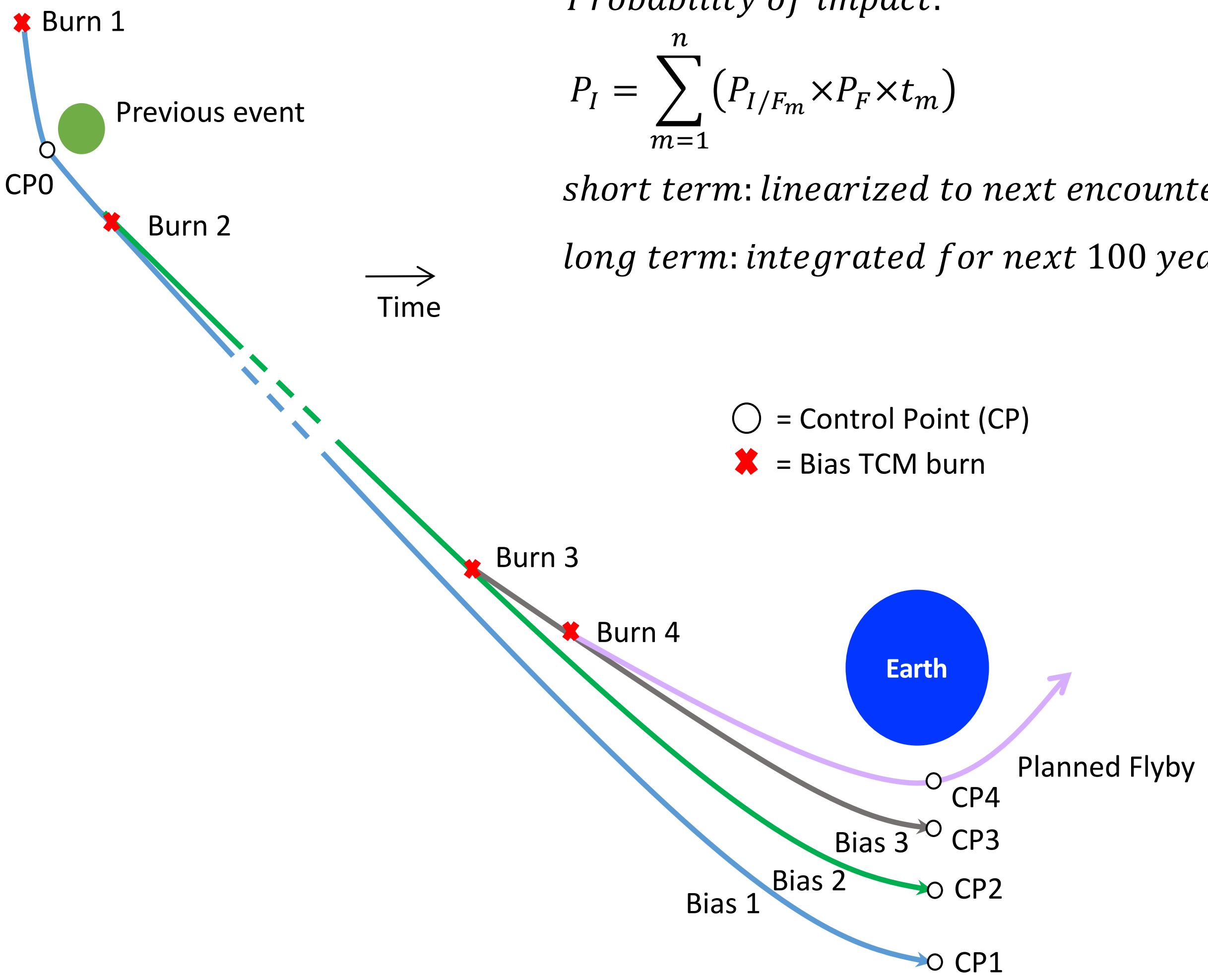


$$\text{Probability of impact:}$$

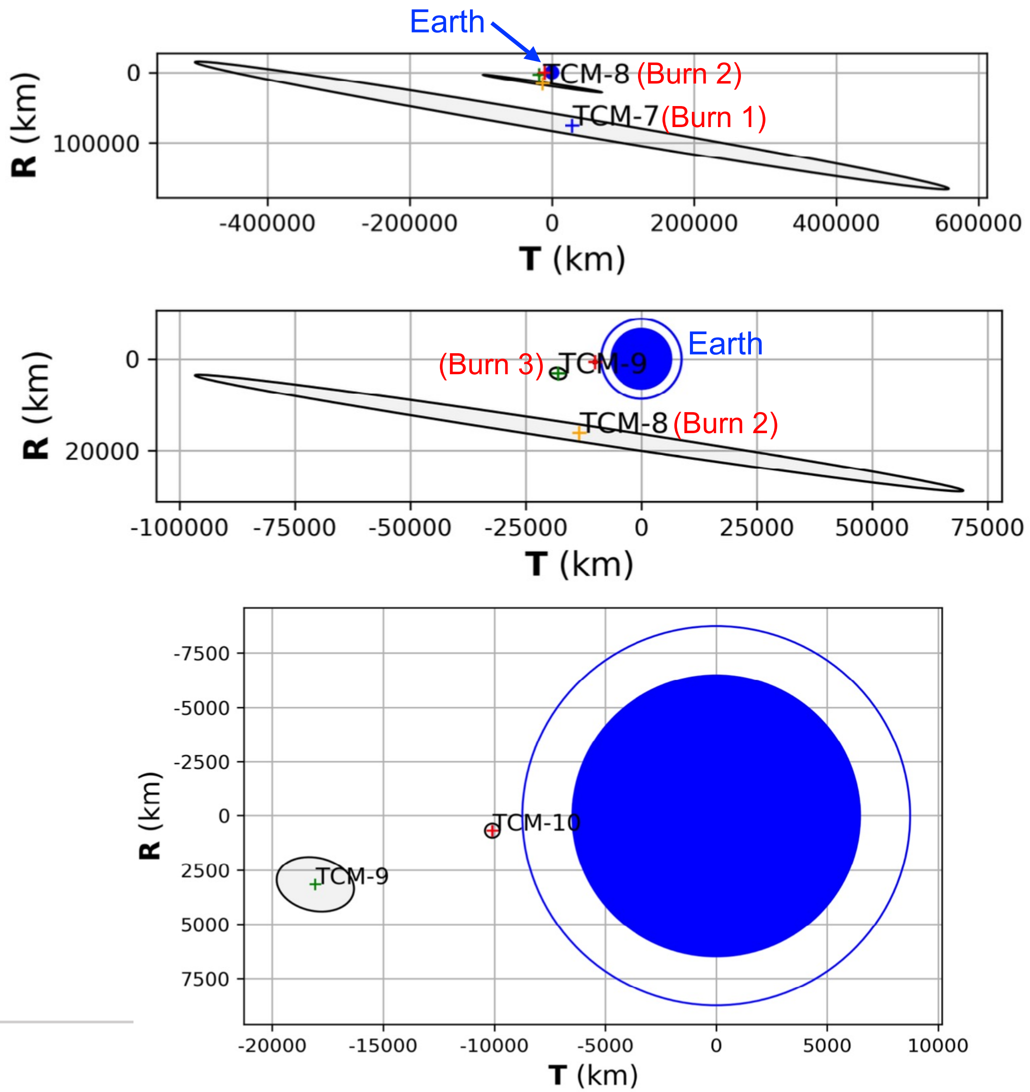
$$P_I = \sum_{m=1}^{n} \left(P_{I/F_m} \times P_F \times t_m\right)$$

$$\text{short term: linearized to next encounter}$$

$$\text{long term: integrated for next 100 years}$$

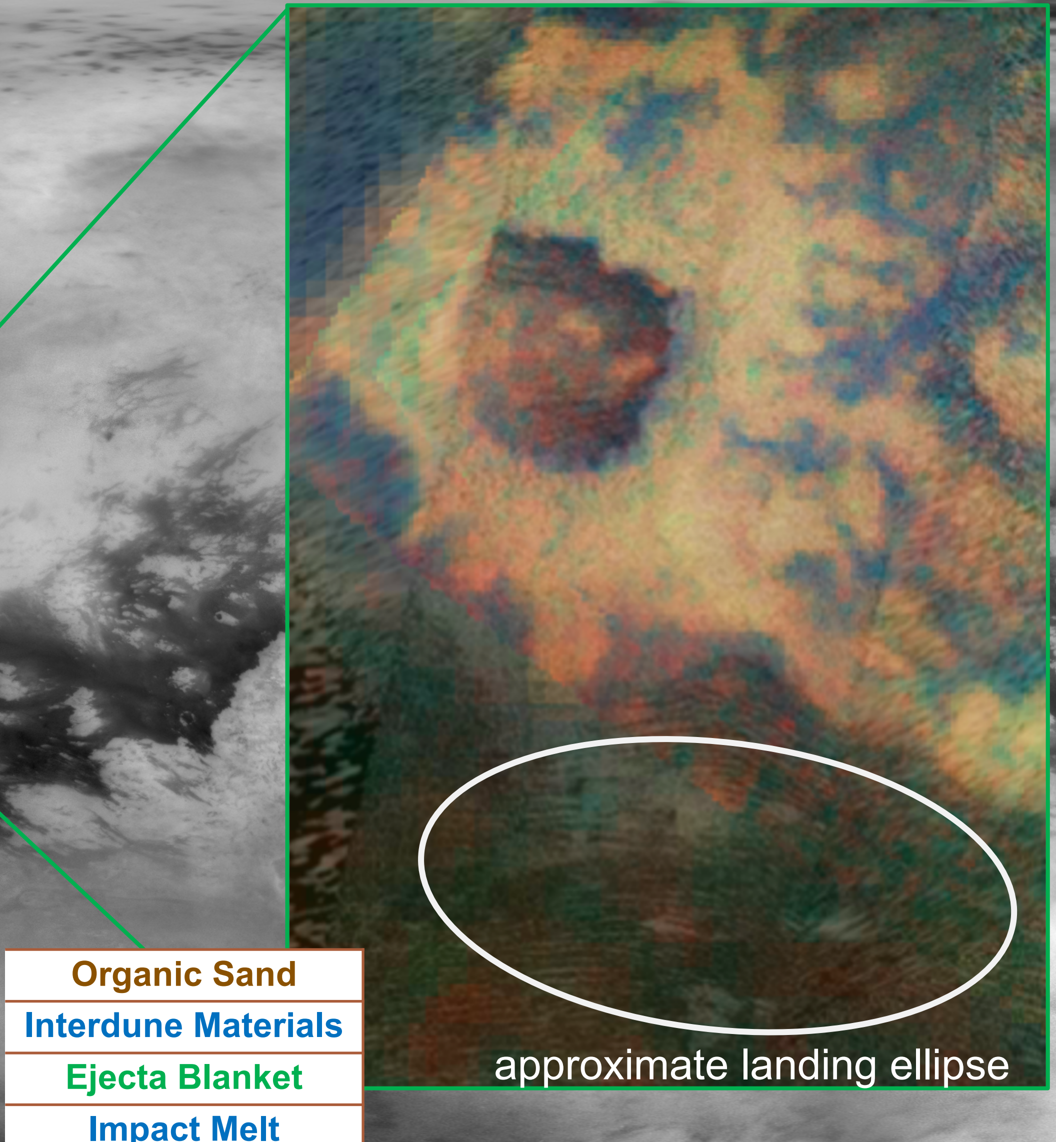


Approach Example: B-Plane view

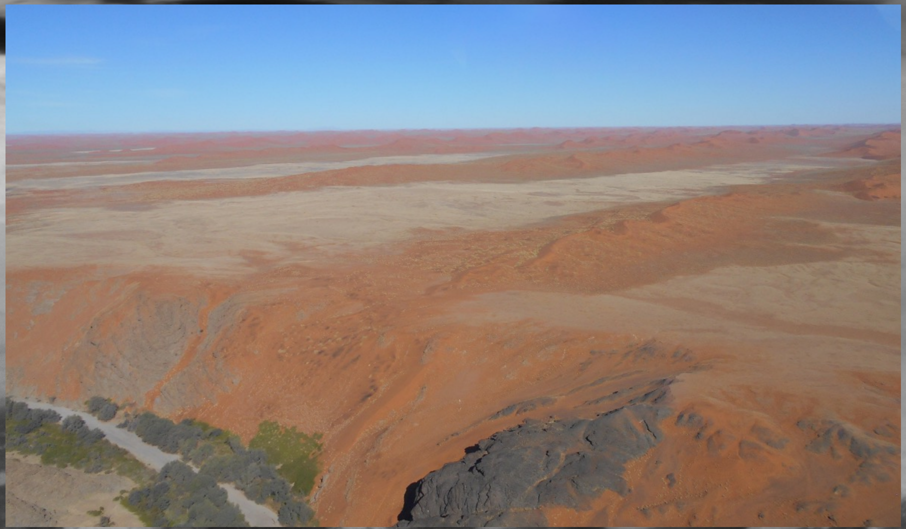


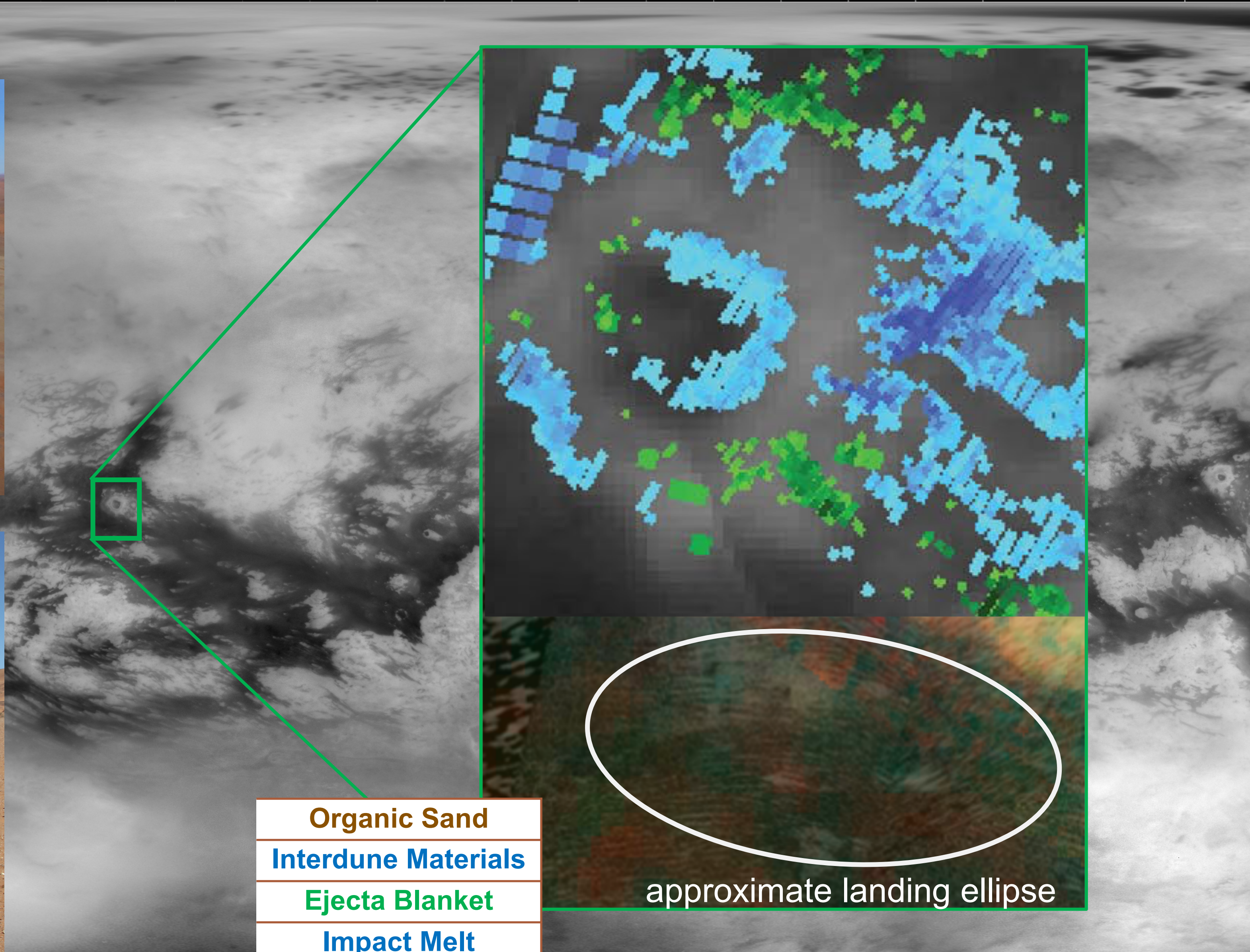
Landing Site and Region of Exploration

- Initial landing site provides access to a variety of materials
  - Sand dunes: organic sediments
  - Interdune areas: materials with a water-ice component
  - Selk impact crater: materials where organics may have mixed with liquid water impact melt

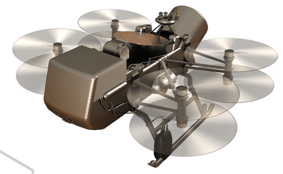


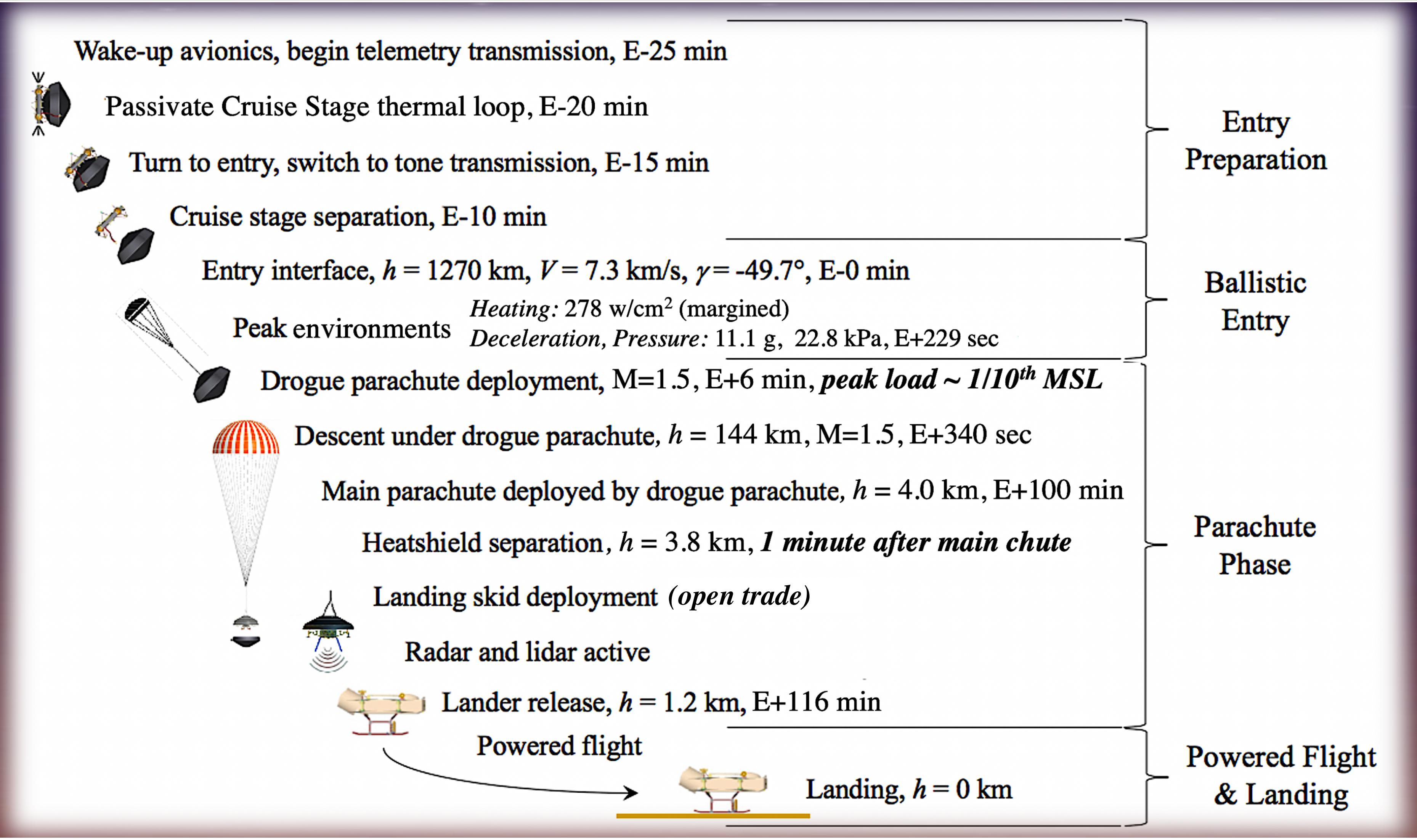
Landing Site and Region of Exploration

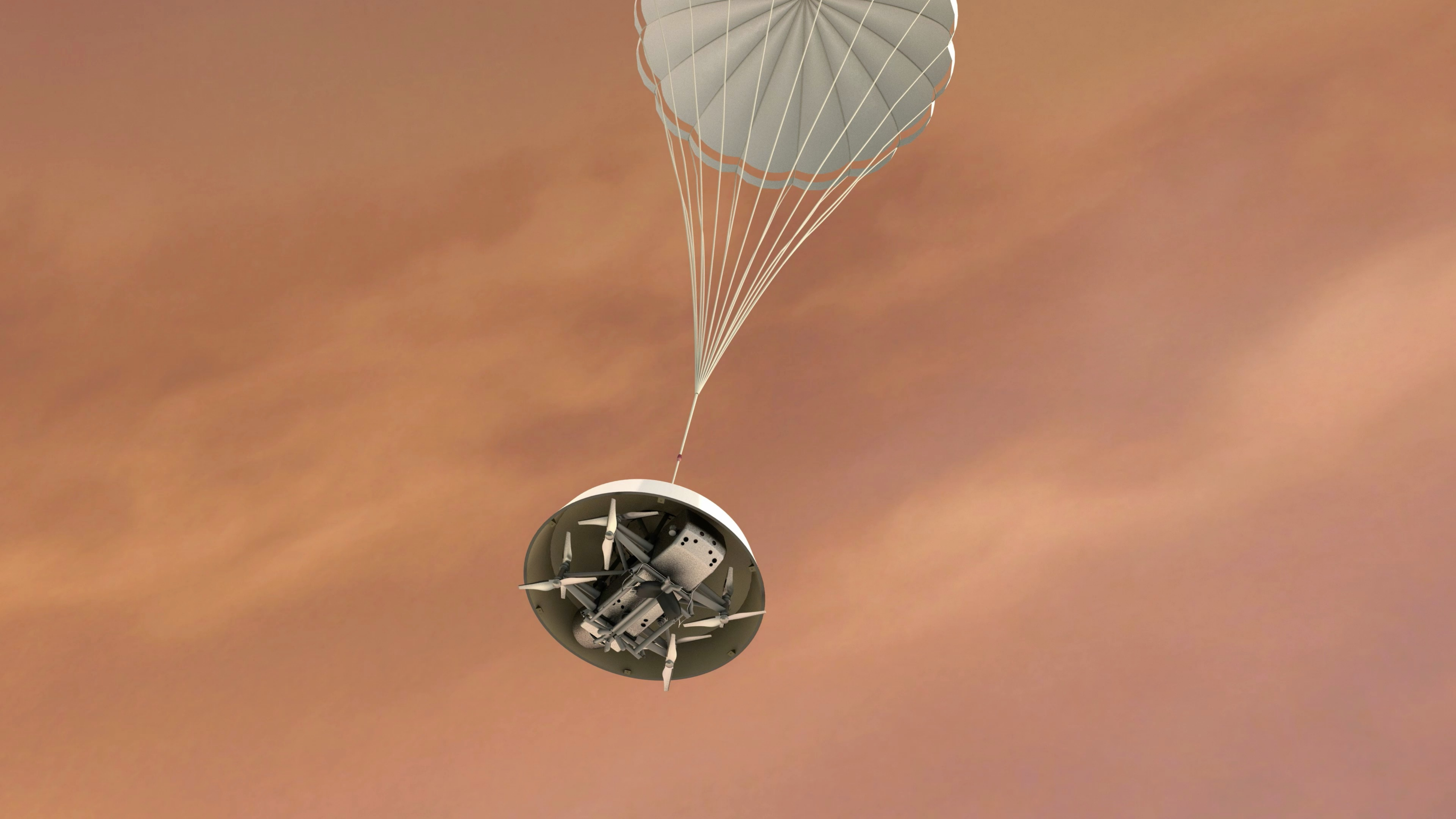




EDL Builds Upon Cassini (and Mars) Legacy





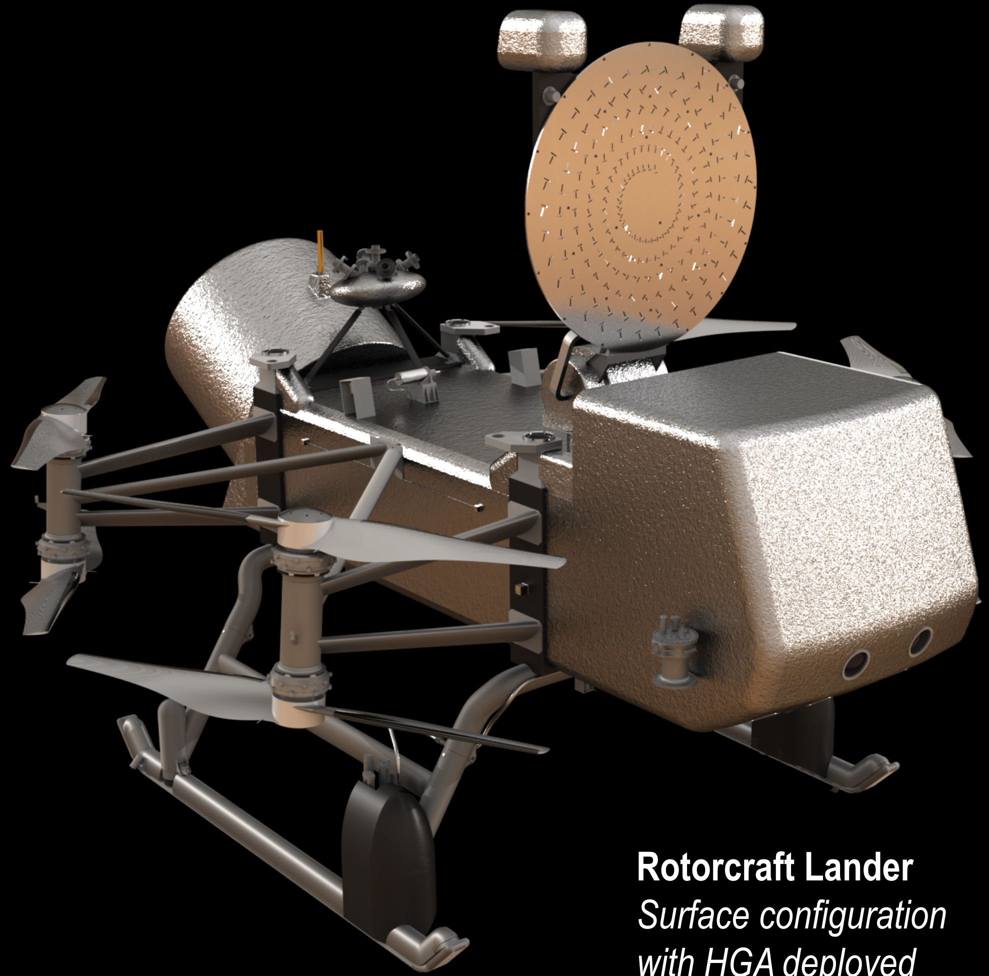


Agenda

- Overview of SE at APL
- Titan Overview
- Conception of Dragonfly
- Innovation, not Invention
- Getting to the Surface
- **Designing for Titan**
- Leveraging Titan's Environment
- Learning to Fly
- Surface ConOps
- It Takes a Village

Lander Facilitated by Focused, Key Attributes

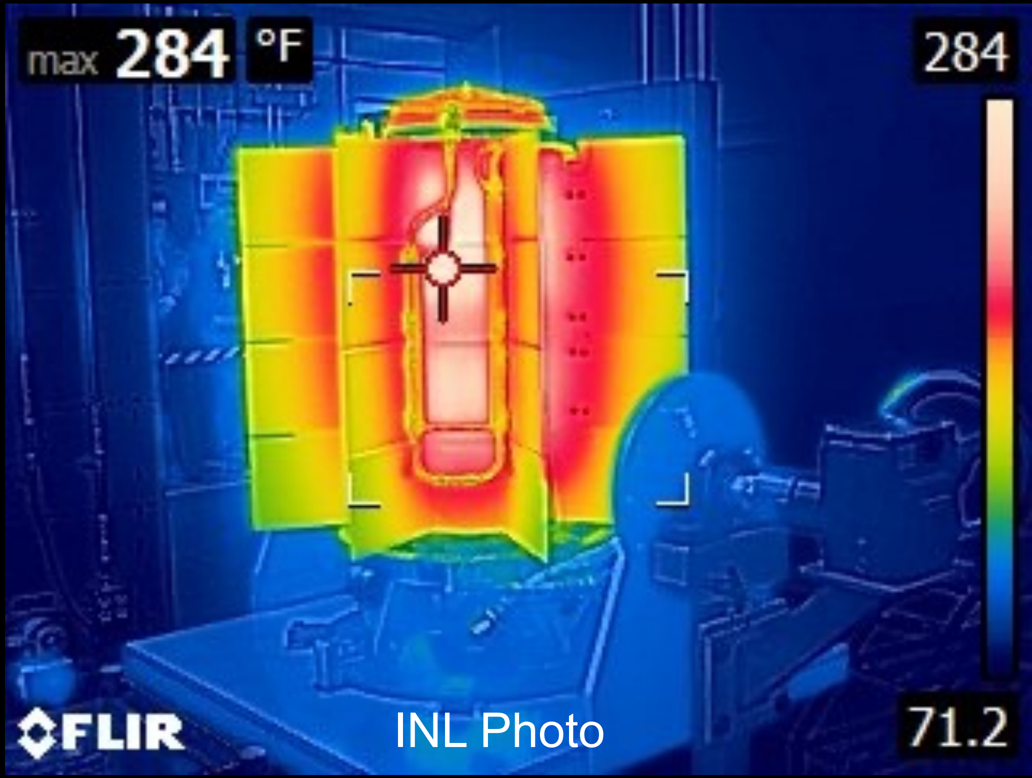
- MMRTG power
  - Charge battery used for flight and science activities
  - Waste heat maintains nominal thermal environment in lander
- Direct-to-Earth communication
  - HGA articulation used to target cameras to build up panoramas of surrounding terrain
- Science measurements predominantly on surface
  - Limited measurements in flight: Aerial imaging and Atmospheric profiles



Rotorcraft Lander
Surface configuration with HGA deployed

Power: MMRTG is a Mission Enabler

- MMRTG * provides nearly 2kW of essential heat, as well as 70-120W of electrical power
- MMRTG can operate in atmosphere

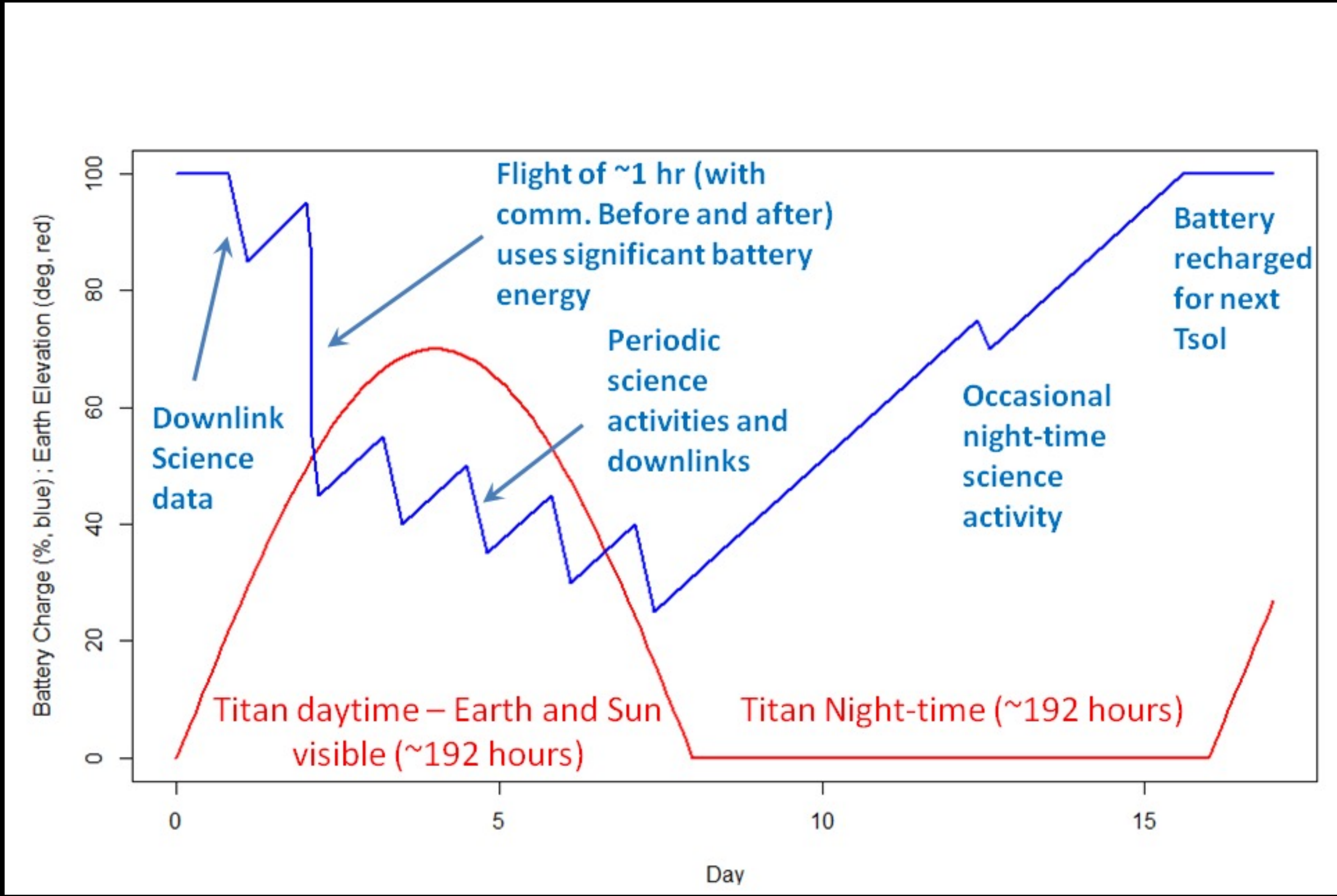


Atmospheric electrical conductivity measurements by Lorenz on F2 MMRTG at Idaho National Laboratory in March 2020. Unit is now on Mars on the Perseverance rover

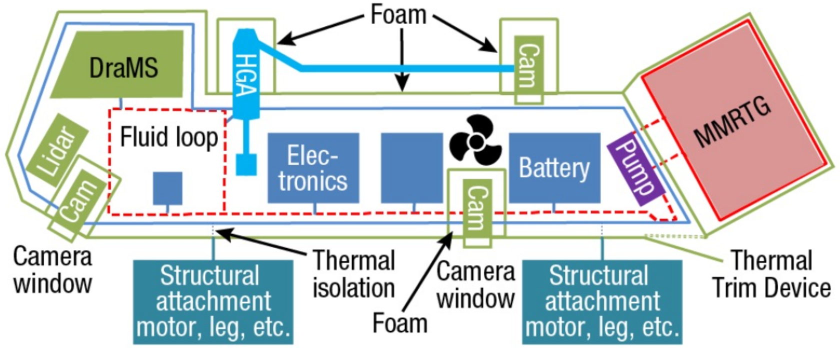
*Use of radioisotope power systems in space is subject to approval per National Environmental Policy Act. Reference to MMRTG usage for Dragonfly is 'pre-decisional'

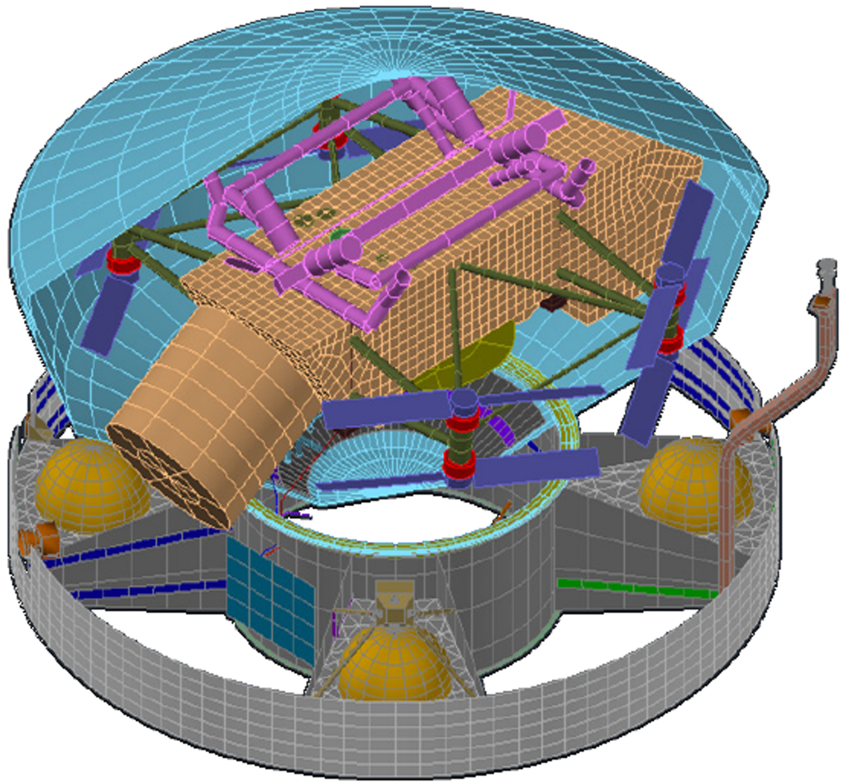
Mission Operations Paced by Energy and Titan Diurnal Cycle

- Hibernation is the default lander state (only essential systems and DraGMet on, battery recharging)
- Battery captures MMRTG output overnight. CONOPS is robust to MMRTG output
- Atmospheric flight, and telecom sessions use most energy

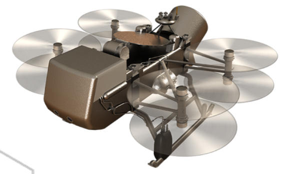


Integrated Thermal Design Utilizes MMRTG Waste Heat to Maintain a Nominal Internal Environment at Titan

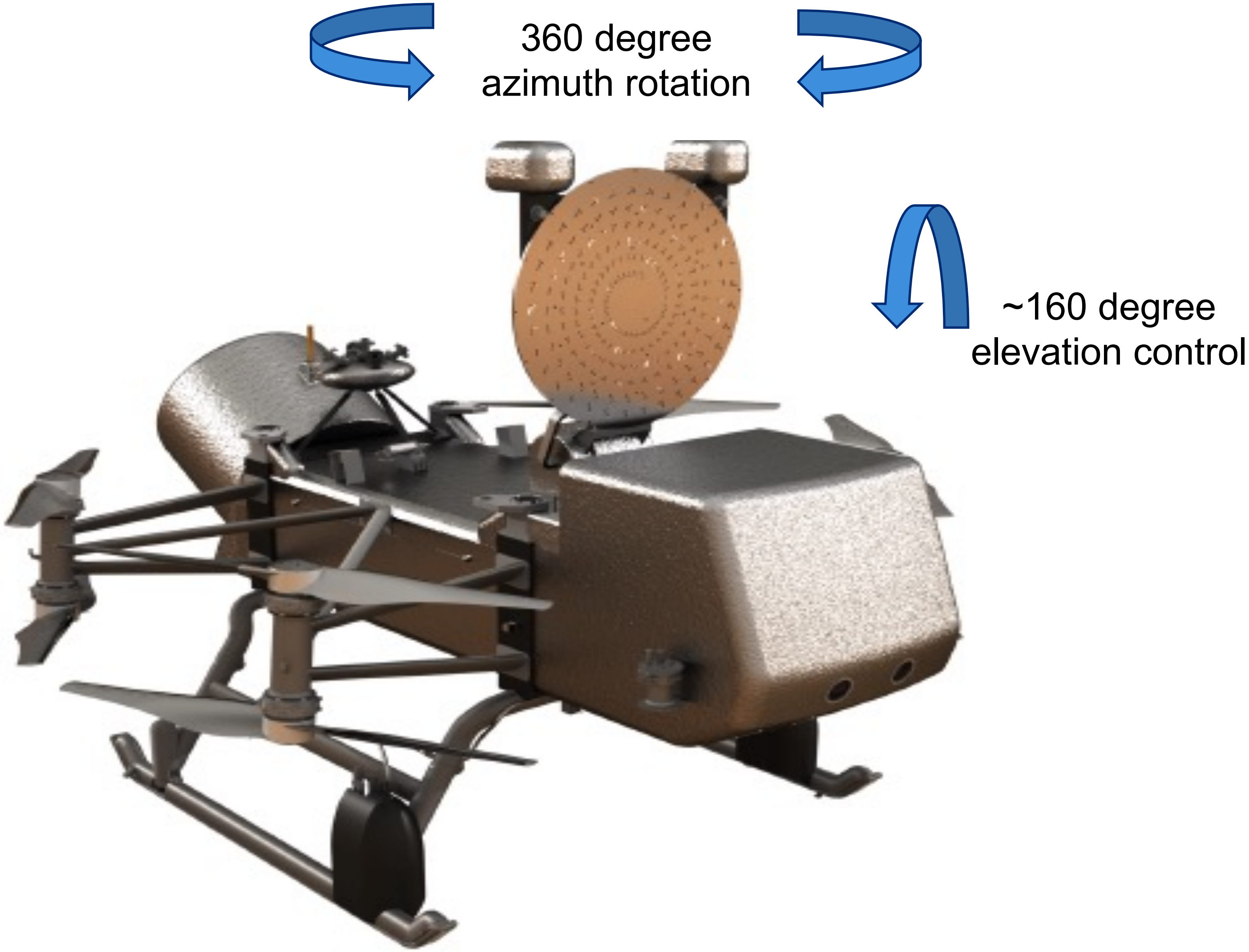




Lander RF Subsystem Supports Direct to Earth Communications from Titan's Surface



- HGA gimbal provides full sky coverage above 10º elevation without interference
- Full data return every 2 Tsols
  - >2 kbps rate expected nominally
  - 1.2 kbps minimum science rate at worst-case distance and elevation

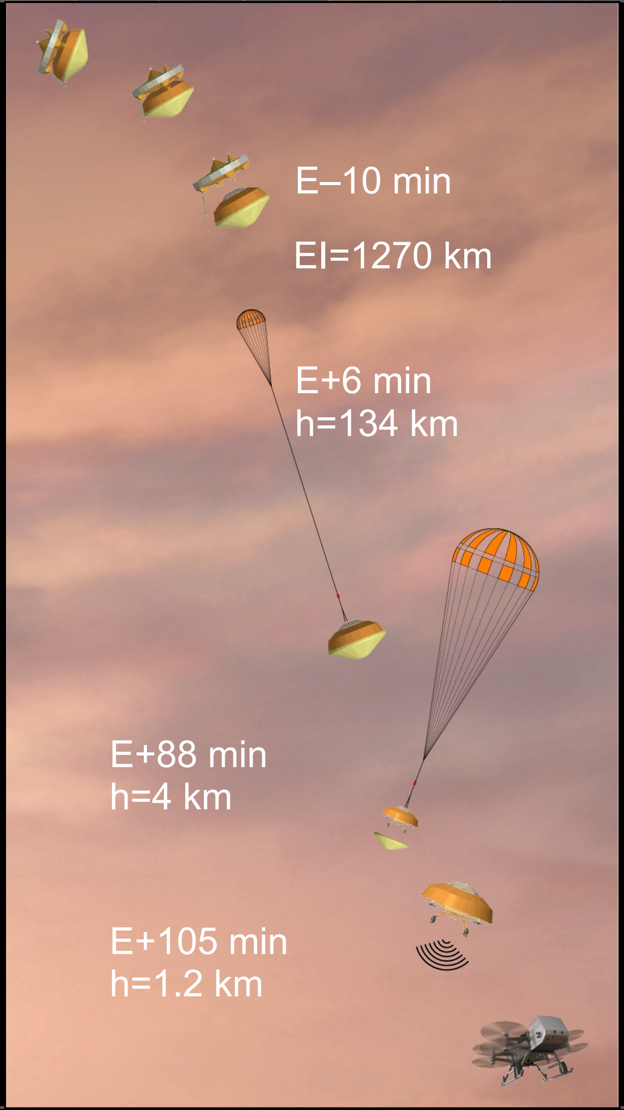


Agenda

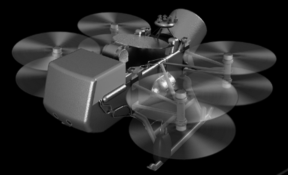
- Overview of SE at APL
- Titan Overview
- Conception of Dragonfly
- Innovation, not Invention
- Getting to the Surface
- Designing for Titan
- **Leveraging Titan's Environment**
- Learning to Fly
- Surface ConOps
- It Takes a Village

Advantages of Titan's environment

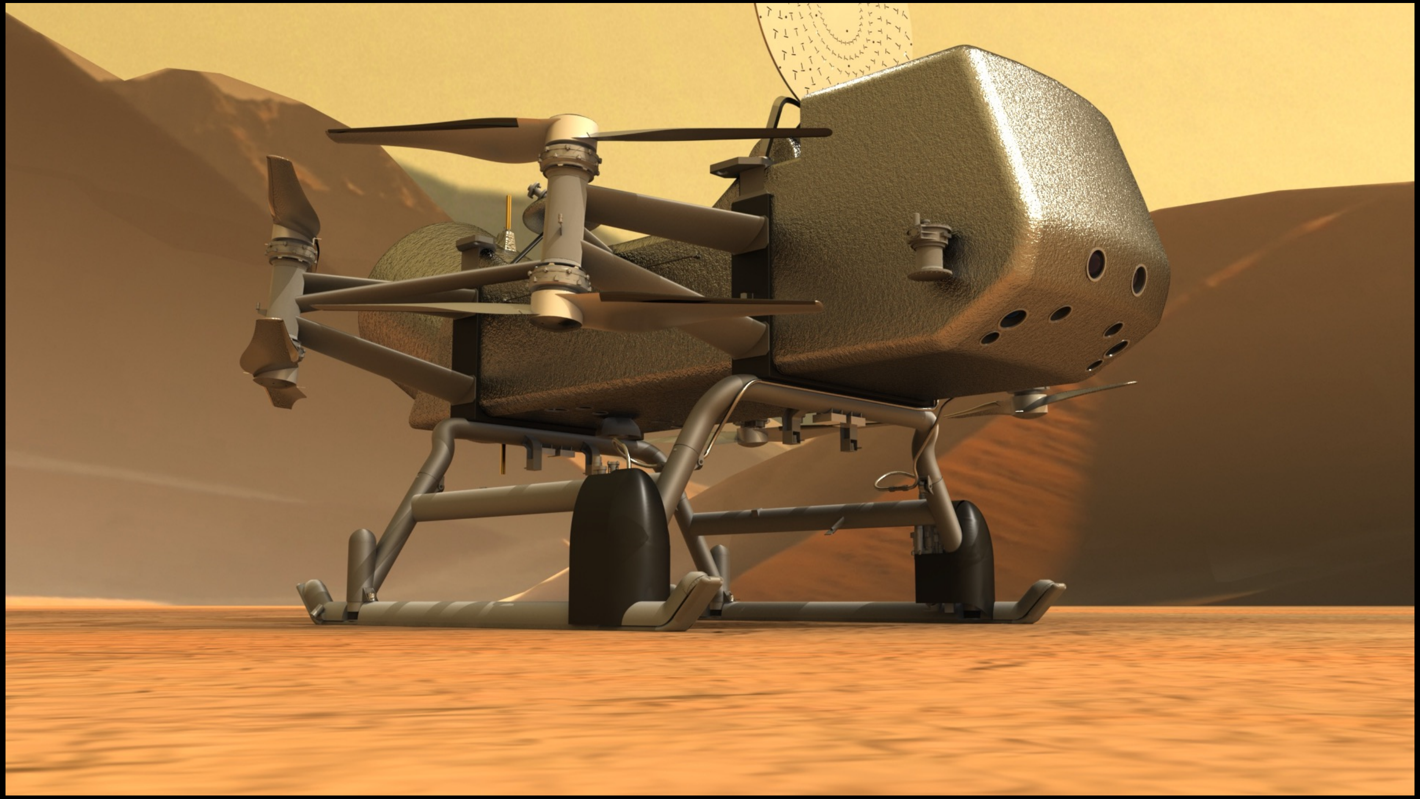
- Dense atmosphere
  - Enables aerial mobility
  - Extended time during EDL
  - Pneumatic sampling
  - Protection from radiation
- 16-day Tsol / orbital period
  - Relaxed operations schedule
- Dense atmosphere + length of day → calm conditions
  - Diurnal, seasonal, and spatial $\Delta T \sim 1$ K
  - Characterized by Cassini-Huygens: Dragonfly arrives 1 Saturn year after Huygens
- Low T → passive cooling
  - Maintain samples (DrACO, DraMS) and sensors (DraGNS) at cryogenic Ts



Advantages of Titan's environment

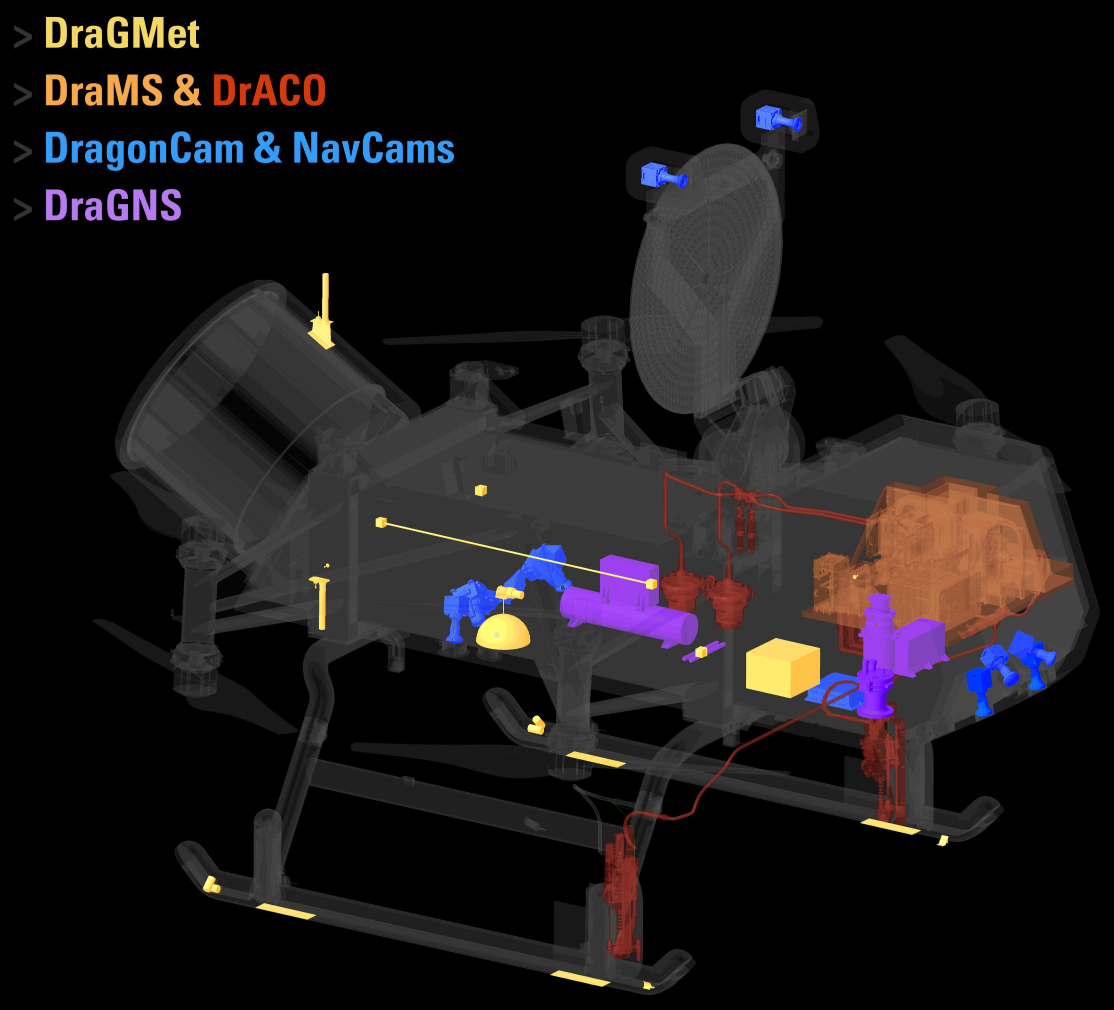


- Dense atmosphere
  - Enables aerial mobility
  - Extended time during EDL
  - Pneumatic sampling
  - Protection from radiation
- 16-day Tsol / orbital period
  - Relaxed operations schedule
- Dense atmosphere + length of day → calm conditions
  - Diurnal, seasonal, and spatial $\Delta T \sim 1$ K
  - Characterized by Cassini-Huygens: Dragonfly arrives 1 Saturn year after Huygens
- Low T → passive cooling
  - Maintain samples (DrACO, DraMS) and sensors (DraGNS) at cryogenic Ts

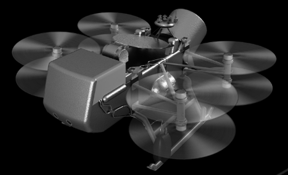


Science goals and payload focus on chemical inventory and opportunities for materials to interact

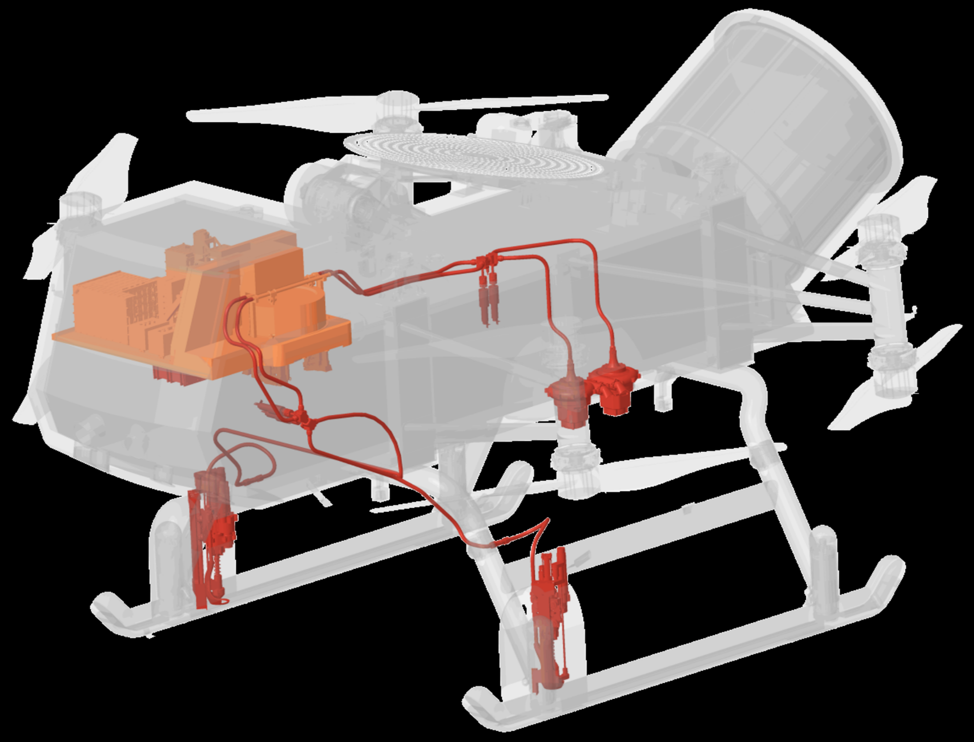
- DraGMet: Geophysics & Meteorology Package (APL, JAXA Lunar-A seismometer)
- DraMS: Mass Spectrometer (GSFC, CNES)
- DrACO: Drill for Acquisition of Complex Organics (Honeybee Robotics)
- DragonCam: Camera Suite (MSSS)
- DraGNS: Gamma-ray Neutron Spectrometer (APL, LLNL, GSFC, Schlumberger PNG)

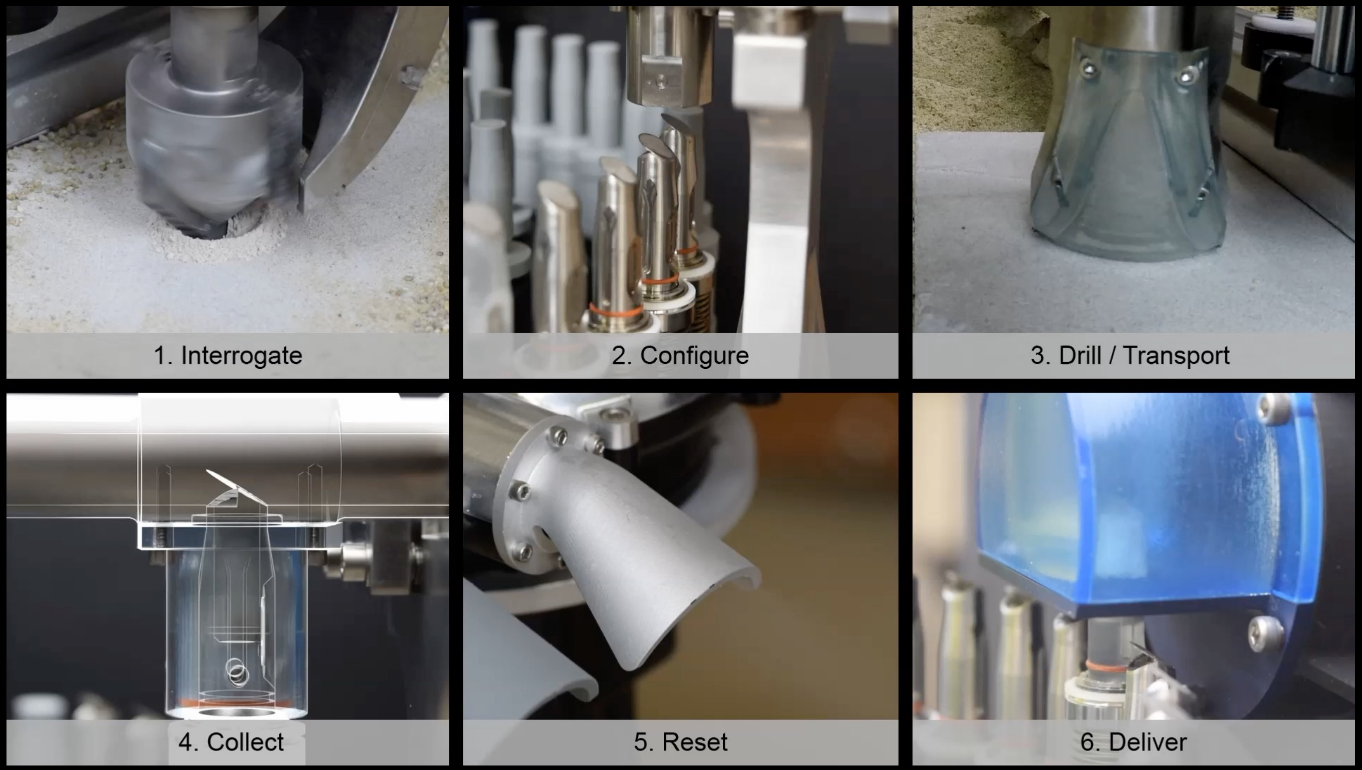


Titan’s Atmosphere Permits Utilization of Pneumatic Transfer to Bring Surface Samples to the DraMS Instrument



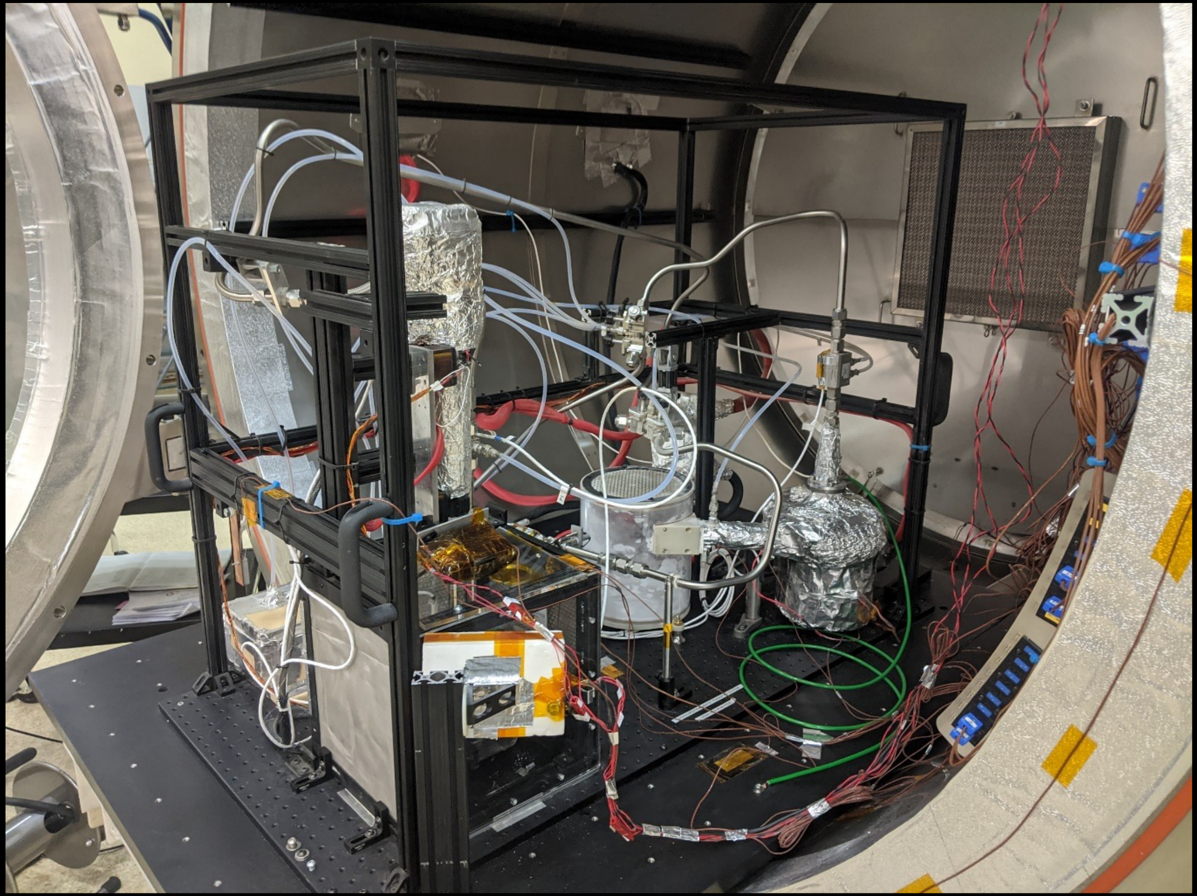
- DrACO uses redundant rotary-percussive drills and blowers to pneumatically transfer surface material to DraMS for detailed chemical analyses





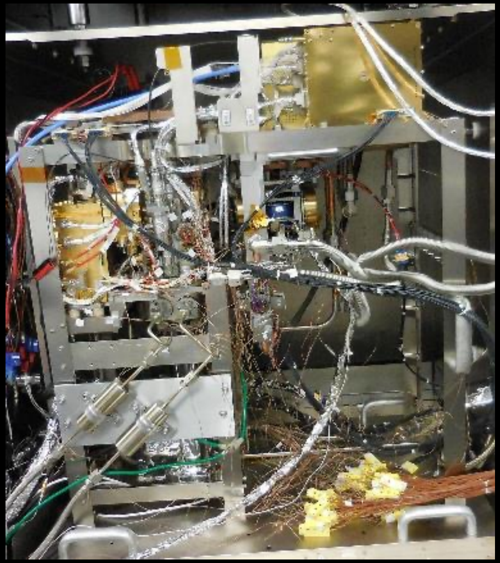
DrACO Pneumatic Transfer System (PTS) Titan Pressure Environment Chamber Testing

- DrACO transports drilled surface samples to the mass spectrometer interface using a Pneumatic Transfer System (PTS)
- A high-fidelity “Brassboard” of the DrACO PTS was tested inside Titan Pressure Environmental Chamber (TPEC) @ APL Nov 2020. **1.5 bar, 94K (N2)**
- Brassboard testing successfully demonstrated pneumatic sample transfer of various simulants in Titan conditions.
- Blower ingested ~12,000 cc, or twice the mission duration’s worth, of abrasive simulant (crushed walnuts) without any observable loss in performance.
- TRL6 test objectives satisfied through successful completion of pneumatic sample transfer and impeller life.

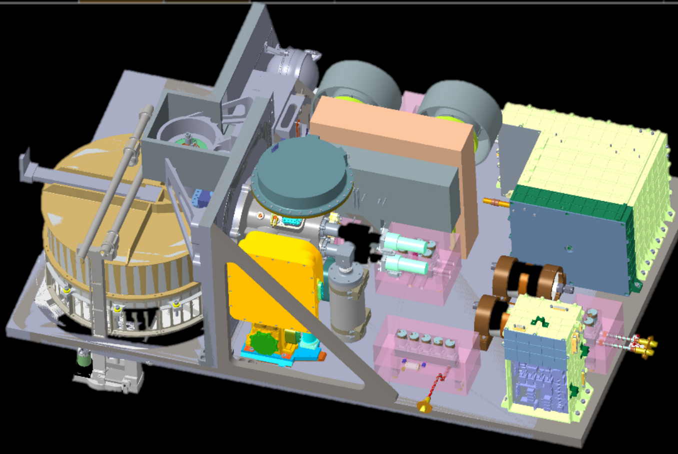


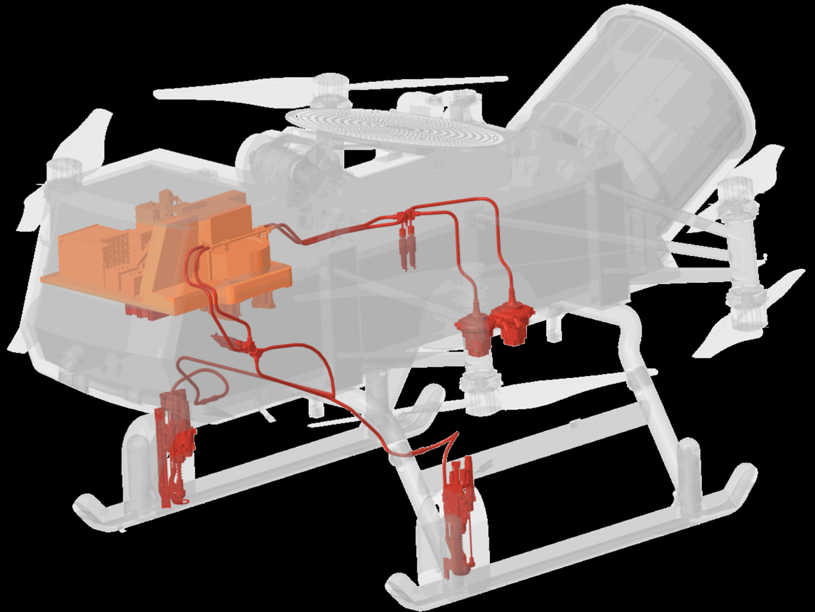
DraMS Based on the Mars Organic Mass Spectrometer (MOMA) instrument on the ExoMars Rover (Delivered 2018, TRL 8)

- Adapt the MOMA architecture so it can straightforwardly be used in the DraMS environment:
  - Adding a backing pump and isolation valve for the MOMA turbopump, to accommodate the thicker Titan atmosphere and long cruise duration.
  - A plumbing split and a water scrubber adapt for the much higher levels of organics and expected water at Titan vs Mars.
  - Rohacell insulation is placed against hot plumbing to limit convection losses.
  - Extreme high voltage discharge control is no longer needed, given the thicker atmosphere.

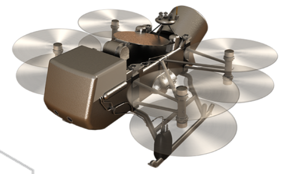


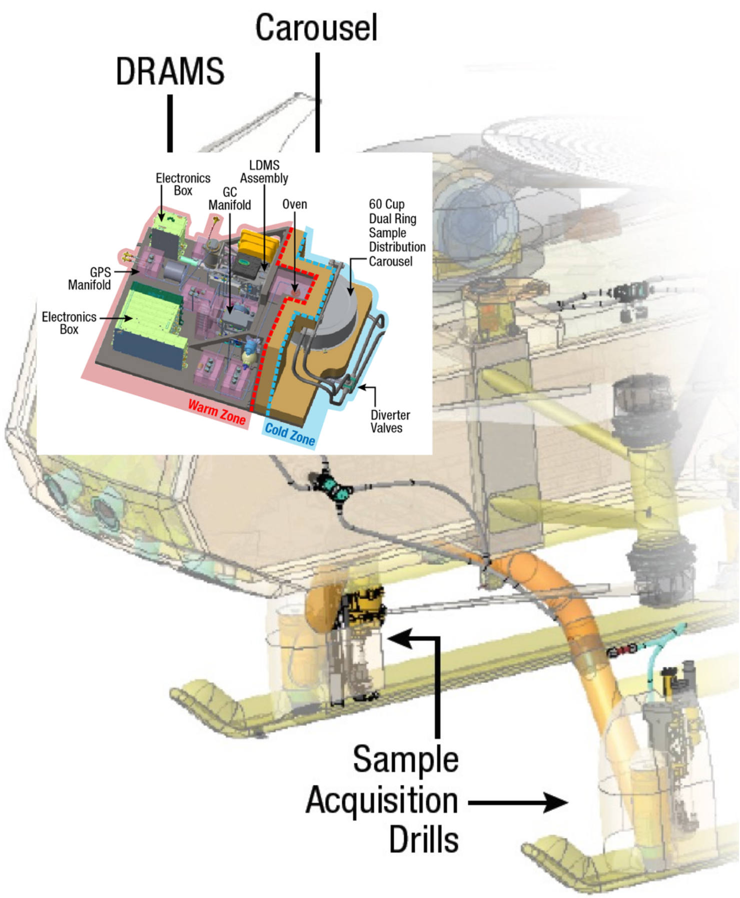
MOMA During Flight Instrument TVAC

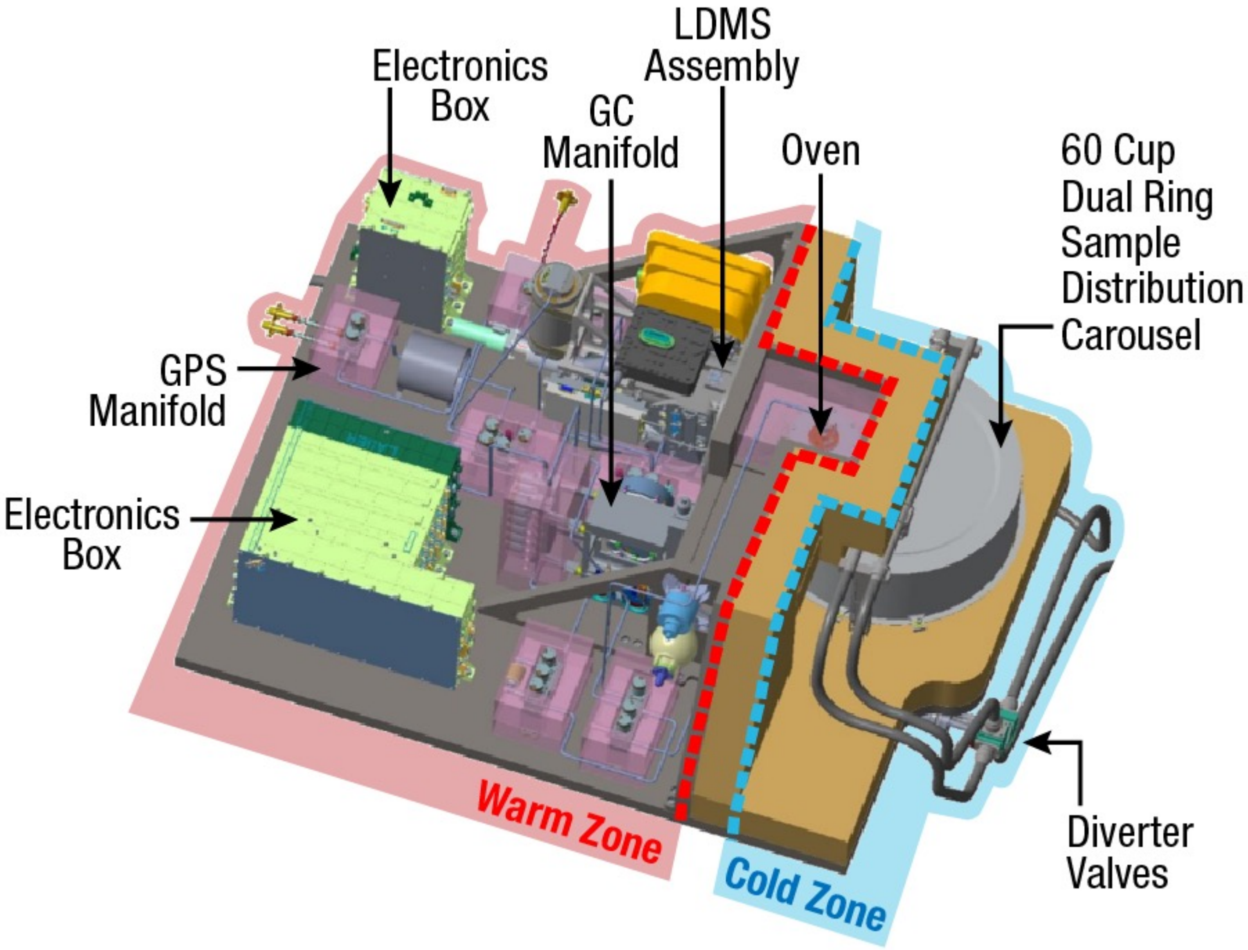




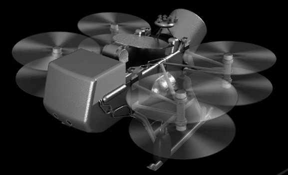
Hot and Cold Zones in Lander Attic Maintain Sample Temperature Near Titan Ambient Until Ingested by DraMS



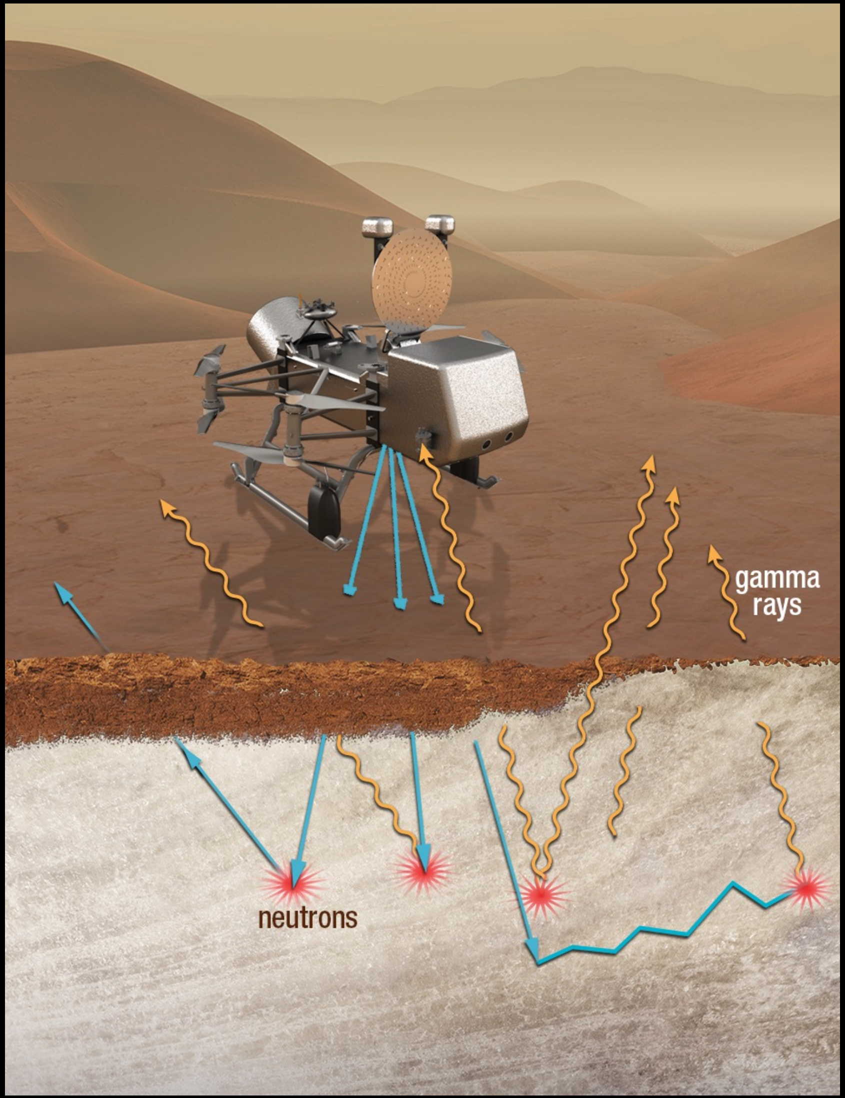


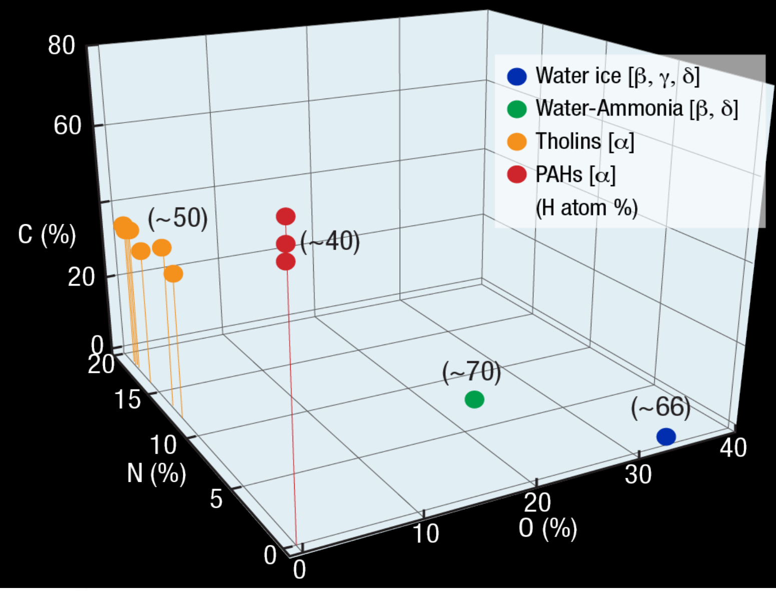


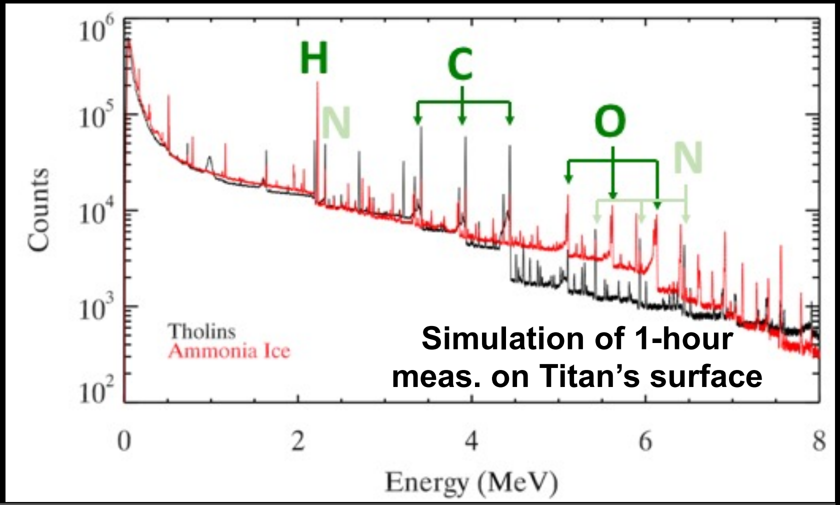
DraGNS Builds Upon Numerous, Proven Orbital Instruments but Must Overcome Titan's Natural Defense from Cosmic Rays



- Measure bulk elemental surface composition
  - Classify surface material
  - Detect minor inorganic elements
  - Reveal near-surface stratigraphy
- Utilizes Pulse Neutron Generator (PNG)
  - Internal neutron source at the surface





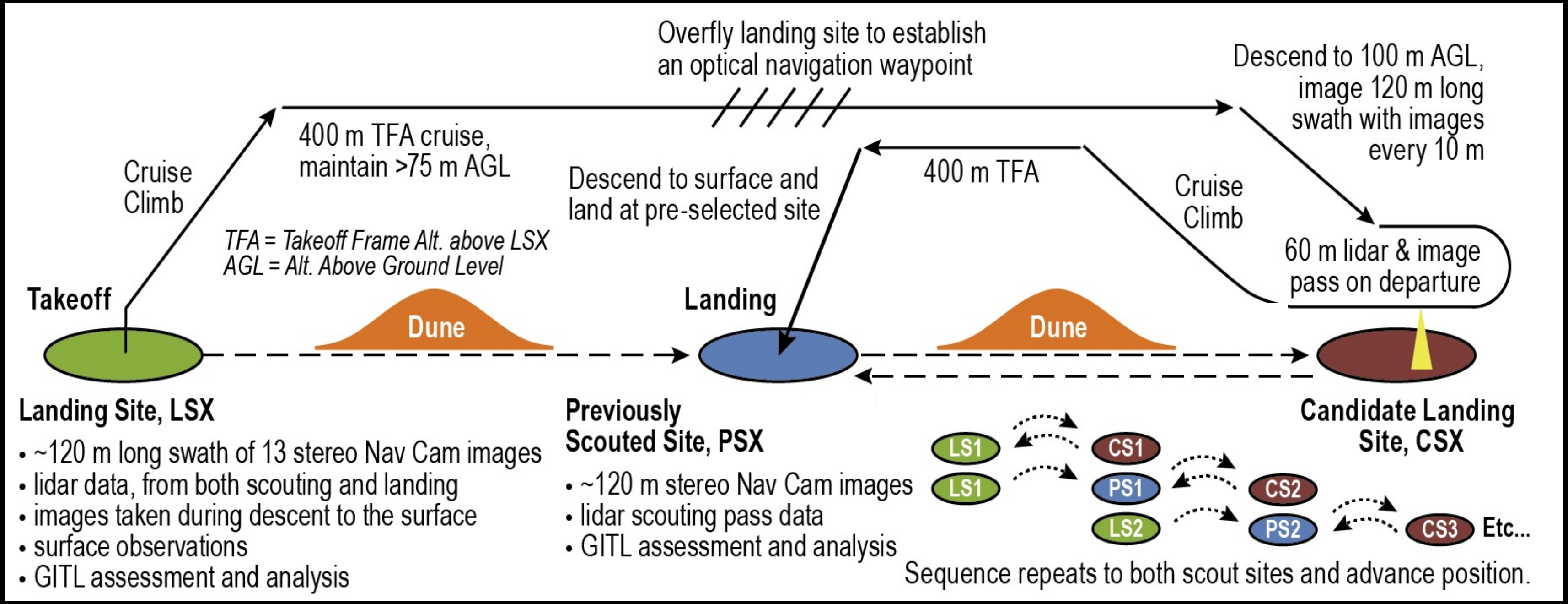


Agenda

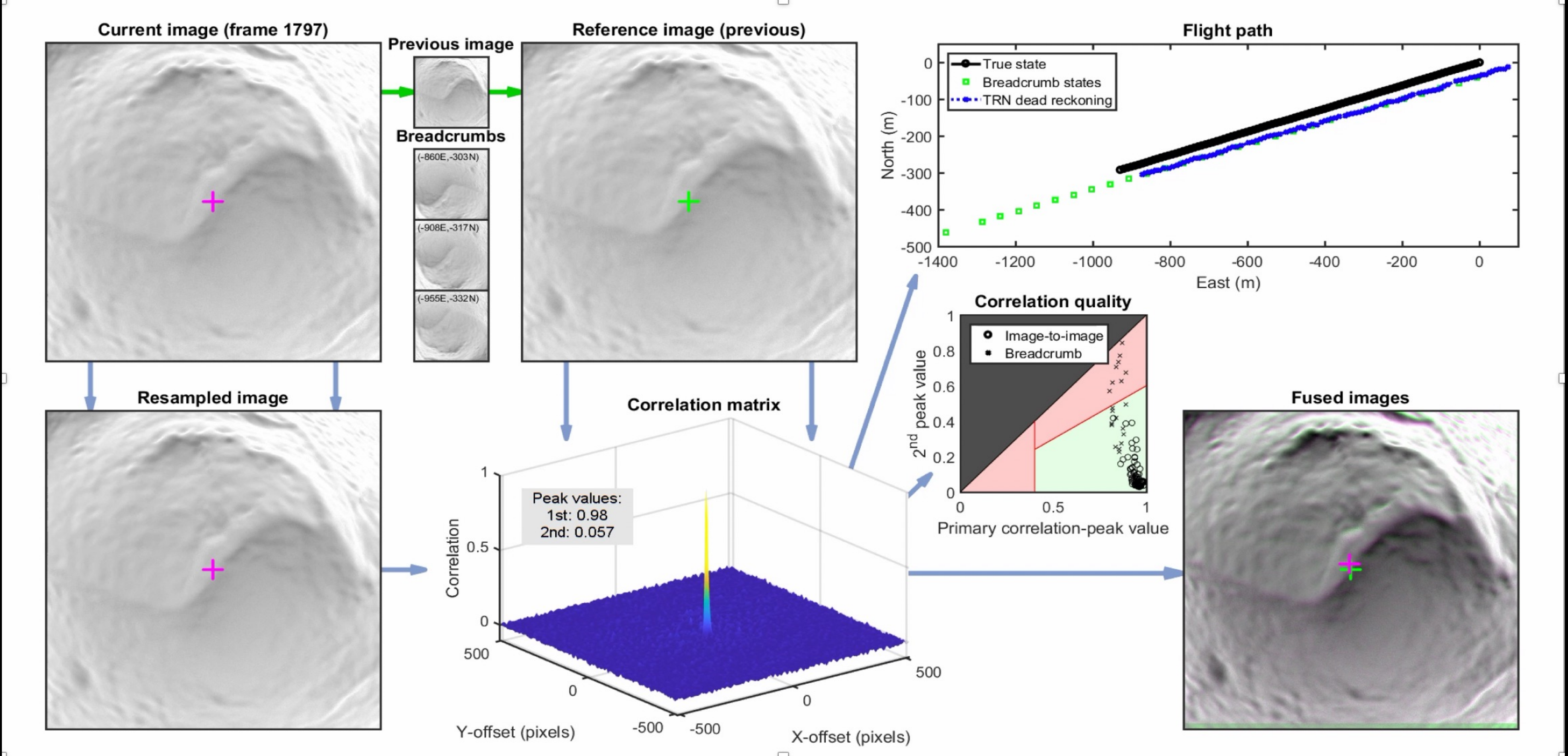
- Overview of SE at APL
- Titan Overview
- Conception of Dragonfly
- Innovation, not Invention
- Getting to the Surface
- Designing for Titan
- Leveraging Titan's Environment
- **Learning to Fly**
- Surface ConOps
- It Takes a Village

Dragonfly Exploration Strategy

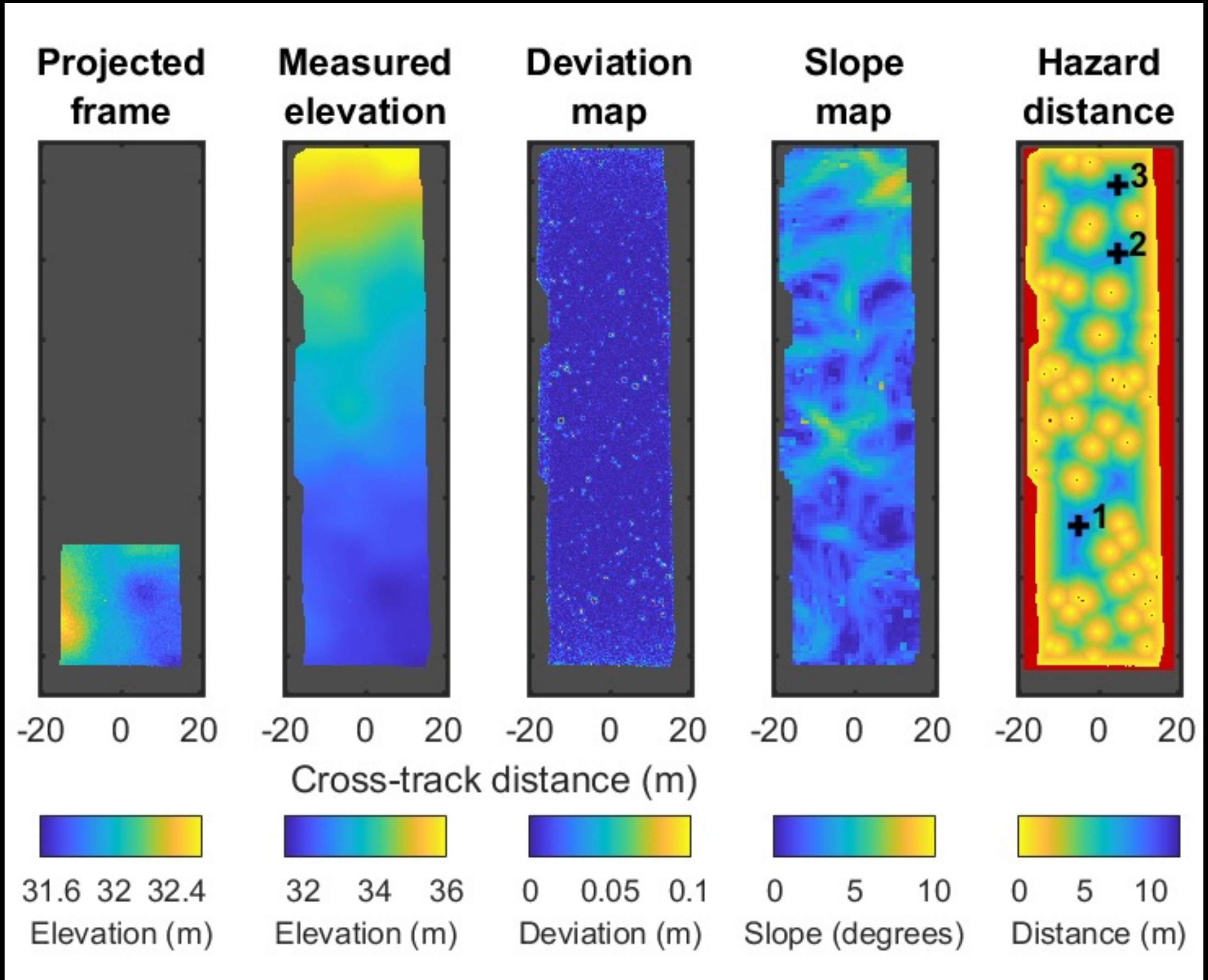
- ~3.3 years of exploration
  - 74 Tsols (Titan days) of science operations
  - Traverse distance up to ~180 km (112 miles)
  - Exploration of ~25-30 unique sites
- "Leapfrog" flights enable scouting of future landing sites
- 16-day Titan sols
  - Nominal flight schedule is once per 2 Tsols (~1 flight / Earth month)
  - Most of time is spent on the surface making science measurements



Optical Navigation under simulated Titan illumination

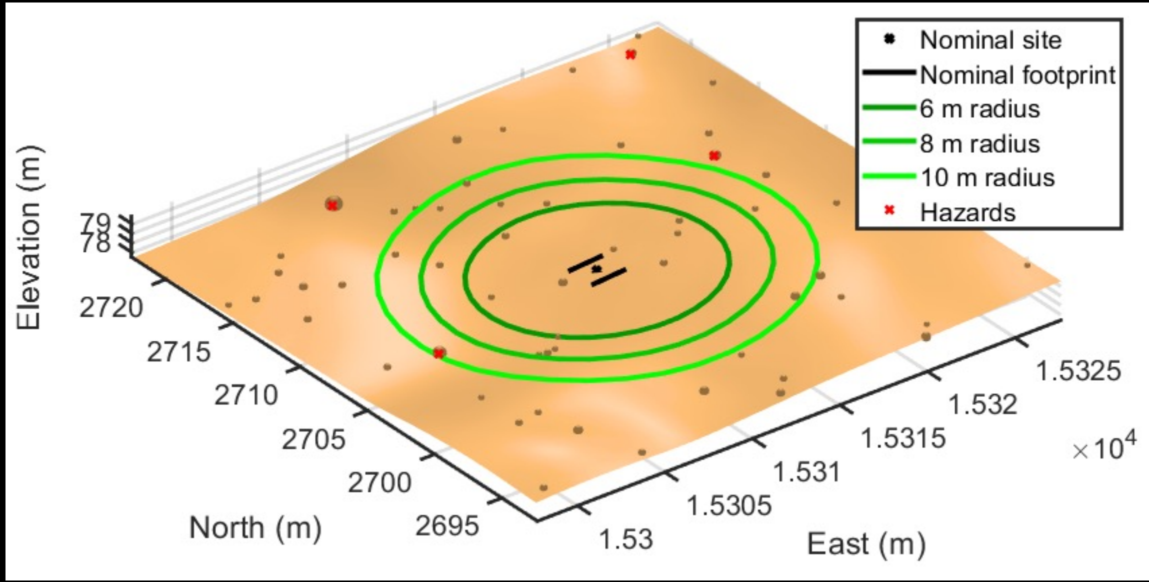


On-board Lidar Hazard Detection and Avoidance

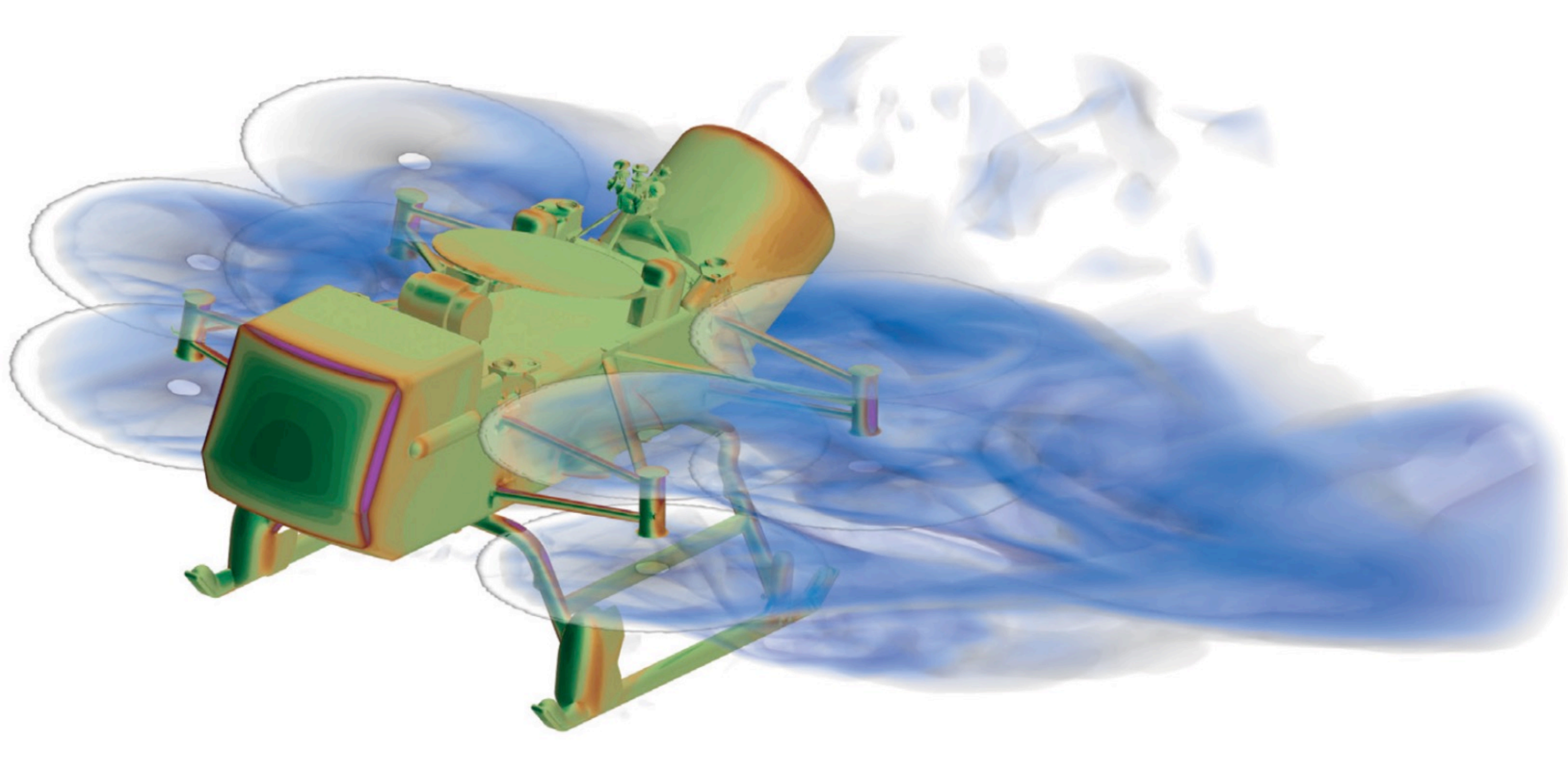


Flash lidar frames fused into map and rock/slope hazards identified

Simulated on 1-m posting satellite DEM of Namib desert (Titan dune analog)



Flight on Titan



CFD simulation by Mike Kinzel (UCF)

Flight on Titan

- CFD validation by wind tunnel tests.
- Rotor tests successfully implemented at NASA Langley 14x22 tunnel (rotor-rotor interaction, at different flow speeds and angles)
- Titan flight conditions (high density, low viscosity) give higher Reynolds number than Earth.
- Blade section for Dragonfly is more typical for wind turbines, relatively insensitive to surface roughness

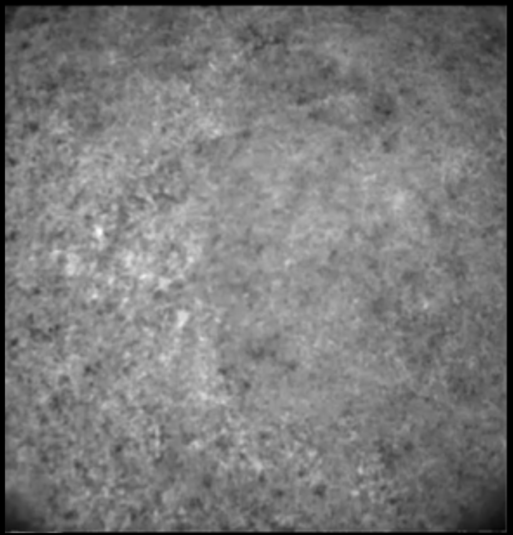
Field Testing of Navigation Systems

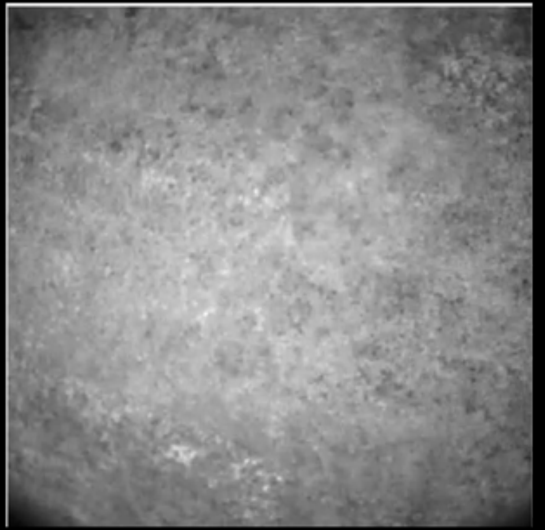
- Demonstrate flight-worthiness of the integrated drone platform under realistic flight profiles; Matching frames and rotor spin direction on actual drone

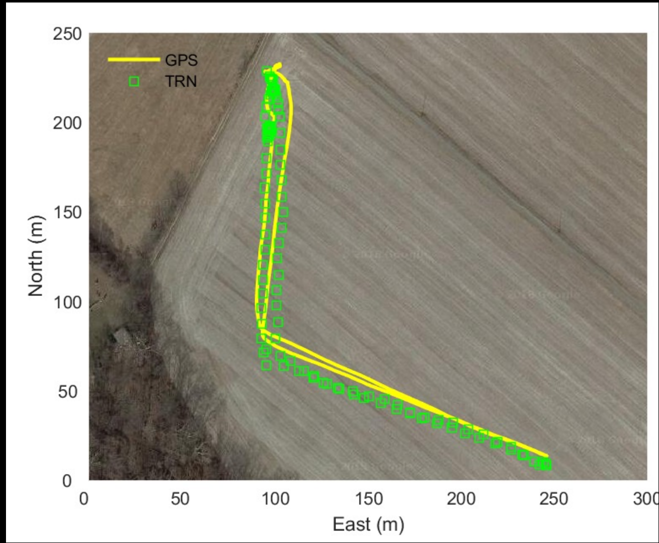
- Control the integrated platform using both ground-piloted (manual) and onboard, autonomous controller sources

- Collect IMU data in-flight for post-processing and performance assessment of the IMU-propagated navigation solution

- TRN Imaging acquisition



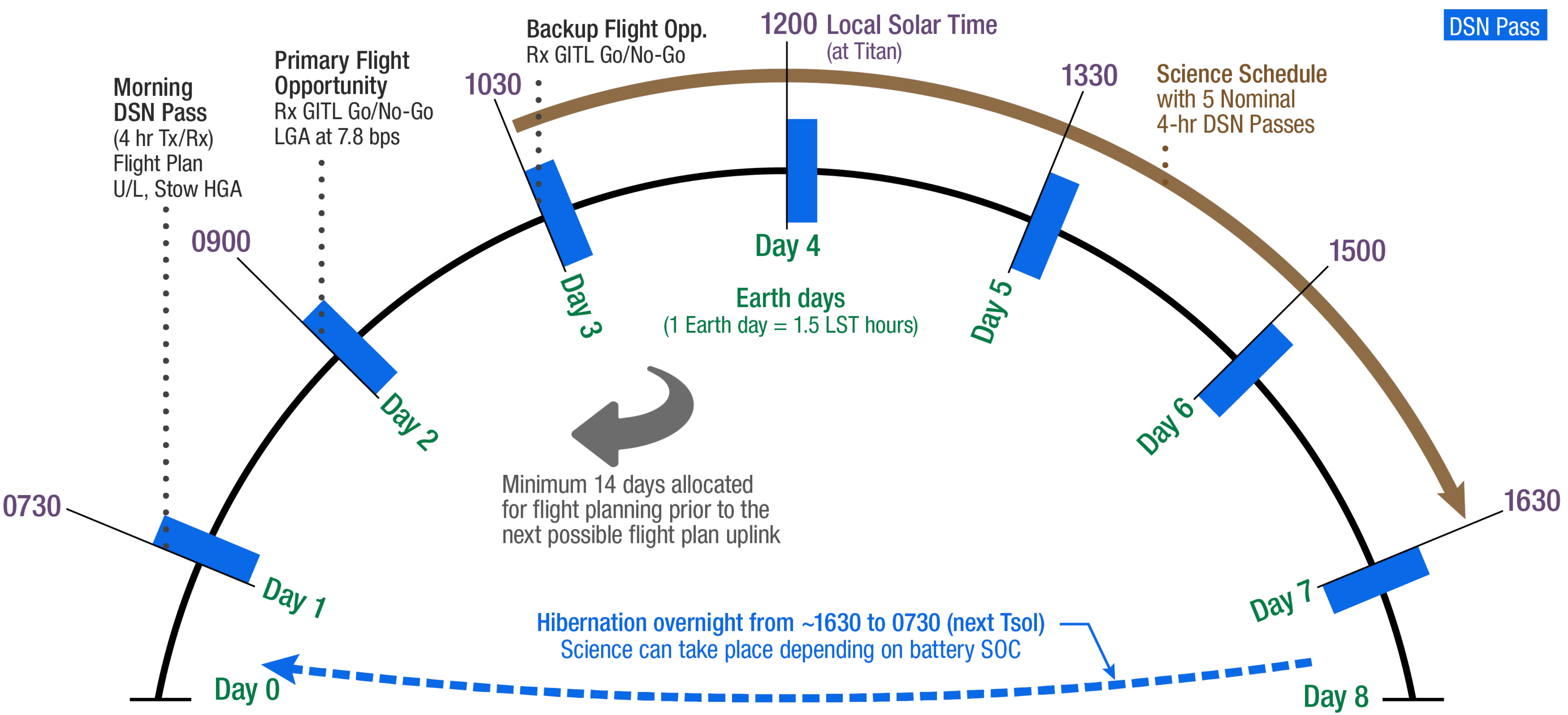




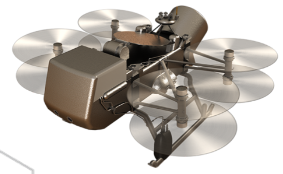
Agenda

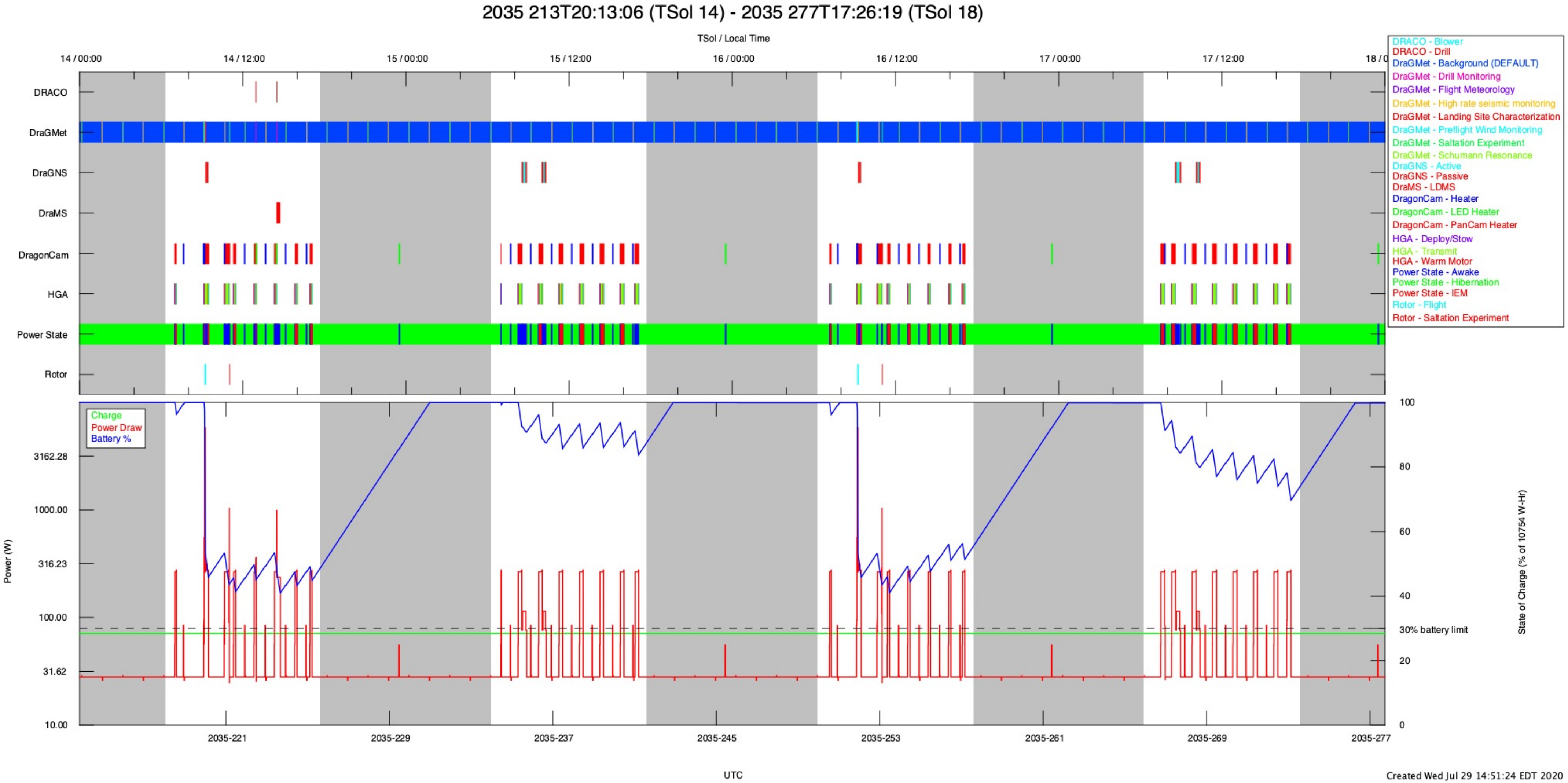
- Overview of SE at APL
- Titan Overview
- Conception of Dragonfly
- Innovation, not Invention
- Getting to the Surface
- Designing for Titan
- Leveraging Titan's Environment
- Learning to Fly
- **Surface ConOps**
- It Takes a Village

Multiple Flight Opportunities, Science Execution, and Earth Communications During a Single Titan Day

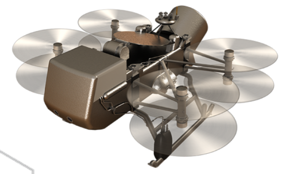


Typical 4 Tsol Sequence – Power Usage and Battery SOC





Typical 4 Tsol Sequence – Data Return Margin



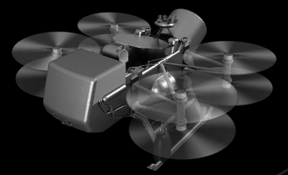
- Sequence inputs:
  - flight + science Tsol followed by downlink Tsol, repeated
  - 2 sites – site characterization by DraGMet & DragonCam, DraGNS measurements, DragonCam stereo panorama, both sites
  - DrACO drilling & DraMS LDMS analysis, 1 site (assume first)
  - Continuous DraGMet meteorologic data, ~40 seismic recordings per Tsol
  - Assumes: 1 battery cell failed, max Titan range
  - Real-time TLM = 10% of 34-m equiv. bandwidth
  - Add'l downlink includes science data, recorded flight + lander TLM
  - All D/L compressed
  - 3.3-yr plan has science margin over baseline requirements:
    - DragonCam/DraGNS at 33 sites vs. 20 req'd
    - 14 LDMS analyses vs. 9 req'd
    - 69 Tsols meteorology vs. 4 req'd

424.1 Mb baseline vs. 807.7 Mb available downlink; 90% margin (30% required)

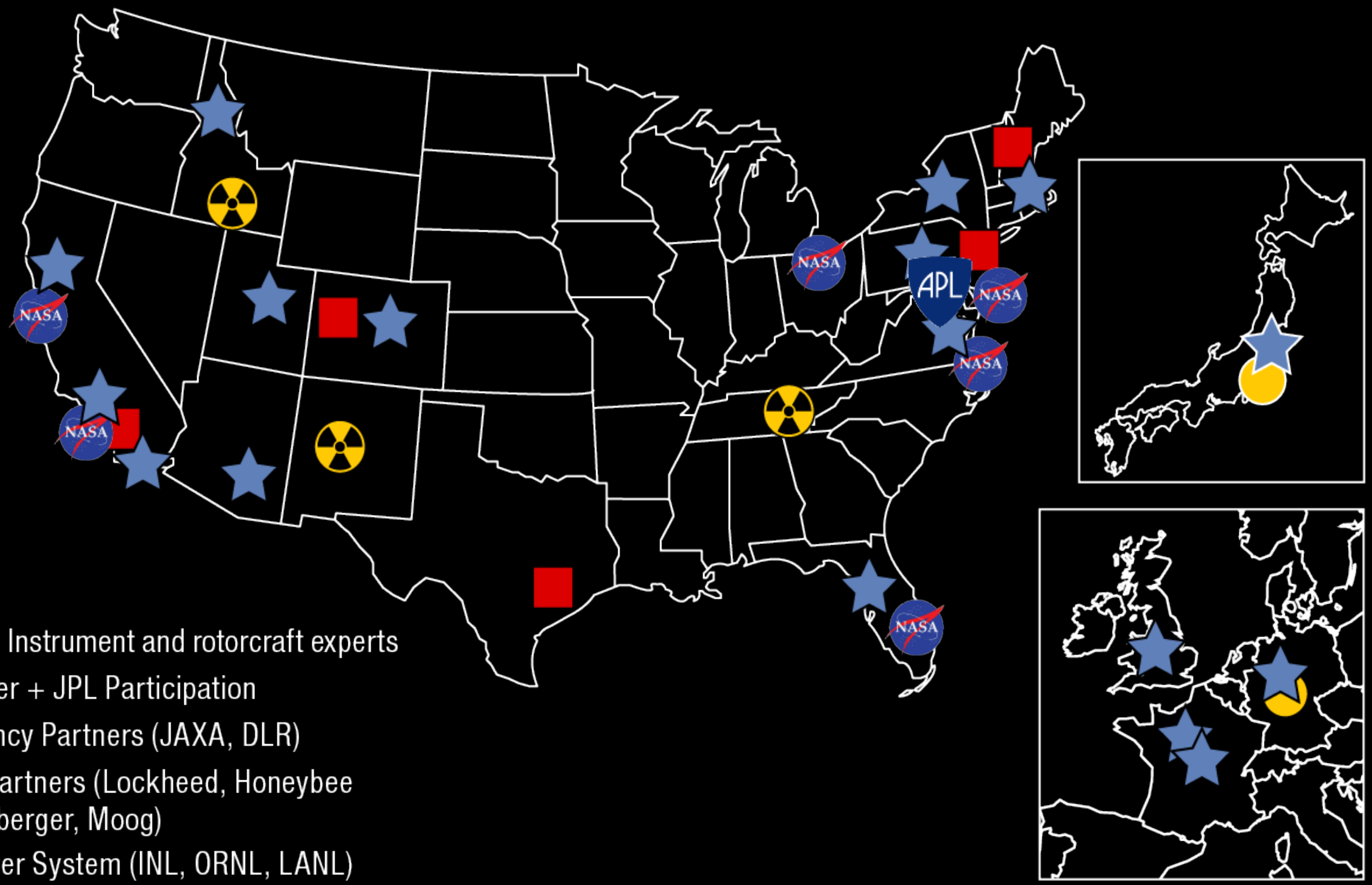
Agenda

- Overview of SE at APL
- Titan Overview
- Conception of Dragonfly
- Innovation, not Invention
- Getting to the Surface
- Designing for Titan
- Leveraging Titan's Environment
- Learning to Fly
- Surface ConOps
- **It Takes a Village**

Dragonfly is an Integrated Team with Broad Representation



- Mission management, lander: APL
- Science payload: GSFC, APL, MSSS, Honeybee Robotics, JAXA, CNES, Schlumberger, LLNL
- Mobility/autonomy: PSU Vertical Lift Research Center of Excellence, APL
- EDL: LaRC, ARC, LM
- Cruise stage and Nav: LM, JPL
- RPS: GRC, ORNL, INL, LANL



Broad representation of NASA Centers, National Labs, universities, industry, and international partners


Exploration and discovery on an ocean world to
determine how far chemistry has progressed in
environments providing key ingredients for life

DRAGONFLY

http://dragonfly.jhuapl.edu

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY